

**Fishery Data Series No. 13-40**

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# **Afognak Lake Sockeye Salmon Stock Monitoring, 2012**

by

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and

**Natura Richardson**

September 2013

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



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<b>Weights and measures (metric)</b>		<b>General</b>		<b>Mathematics, statistics</b>	
centimeter	cm	Alaska Administrative		<i>all standard mathematical</i>	
deciliter	dL	Code	AAC	<i>signs, symbols and</i>	
gram	g	all commonly accepted		<i>abbreviations</i>	
hectare	ha	abbreviations	e.g., Mr., Mrs.,	alternate hypothesis	H <sub>A</sub>
kilogram	kg		AM, PM, etc.	base of natural logarithm	<i>e</i>
kilometer	km	all commonly accepted		catch per unit effort	CPUE
liter	L	professional titles	e.g., Dr., Ph.D.,	coefficient of variation	CV
meter	m		R.N., etc.	common test statistics	(F, t, $\chi^2$ , etc.)
milliliter	mL	at	@	confidence interval	CI
millimeter	mm	compass directions:		correlation coefficient	
		east	E	(multiple)	R
		north	N	correlation coefficient	
		south	S	(simple)	r
		west	W	covariance	cov
		copyright	©	degree (angular )	°
		corporate suffixes:		degrees of freedom	df
		Company	Co.	expected value	<i>E</i>
		Corporation	Corp.	greater than	>
		Incorporated	Inc.	greater than or equal to	≥
		Limited	Ltd.	harvest per unit effort	HPUE
		District of Columbia	D.C.	less than	<
		et alii (and others)	et al.	less than or equal to	≤
		et cetera (and so forth)	etc.	logarithm (natural)	ln
		exempli gratia		logarithm (base 10)	log
		(for example)	e.g.	logarithm (specify base)	log <sub>2</sub> , etc.
		Federal Information		minute (angular)	'
		Code	FIC	not significant	NS
		id est (that is)	i.e.	null hypothesis	H <sub>0</sub>
		latitude or longitude	lat. or long.	percent	%
		monetary symbols		probability	P
		(U.S.)	\$, ¢	probability of a type I error	
		months (tables and		(rejection of the null	
		figures): first three		hypothesis when true)	α
		letters	Jan,...,Dec	probability of a type II error	
		registered trademark	®	(acceptance of the null	
		trademark	™	hypothesis when false)	β
		United States		second (angular)	"
		(adjective)	U.S.	standard deviation	SD
		United States of		standard error	SE
		America (noun)	USA	variance	
		U.S.C.	United States	population	Var
			Code	sample	var
		U.S. state	use two-letter		
			abbreviations		
			(e.g., AK, WA)		
<b>Weights and measures (English)</b>					
cubic feet per second	ft <sup>3</sup> /s				
foot	ft				
gallon	gal				
inch	in				
mile	mi				
nautical mile	nmi				
ounce	oz				
pound	lb				
quart	qt				
yard	yd				
<b>Time and temperature</b>					
day	d				
degrees Celsius	°C				
degrees Fahrenheit	°F				
degrees kelvin	K				
hour	h				
minute	min				
second	s				
<b>Physics and chemistry</b>					
all atomic symbols					
alternating current	AC				
ampere	A				
calorie	cal				
direct current	DC				
hertz	Hz				
horsepower	hp				
hydrogen ion activity	pH				
(negative log of)					
parts per million	ppm				
parts per thousand	ppt,				
	‰				
volts	V				
watts	W				

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**AFOGNAK LAKE SOCKEYE SALMON STOCK MONITORING, 2012**

by

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# ABSTRACT

The Afognak Lake sockeye salmon *Oncorhynchus nerka* run severely declined in 2001. Concerns expressed by local subsistence users to the Alaska Department of Fish and Game and the US Fish and Wildlife Service Office of Subsistence Management prompted an investigation of Afognak Lake's rearing environment in 2003 followed by subsequent annual studies. This report provides 2012 project results.

An estimated 127,862 sockeye salmon smolt (95% CI 98,551–157,173) outmigrated from Afognak Lake in 2012, based on established mark-recapture techniques. The outmigrating sockeye salmon smolt population was composed of 99,541 freshwater-age-1 and 28,321 freshwater-age-2 smolt. Freshwater-age-1 smolt had a mean weight of 3.1 g, a mean length of 73 mm, and a mean condition factor of 0.81. Freshwater-age-2 smolt had a mean weight of 3.9 g, a mean length of 79 mm, and a mean condition factor of 0.78. The total adult sockeye salmon escapement into Afognak Lake was 41,553 fish; of which 56.7% were age 1.3, 15.7% were 1.2, and 14.0% were 2.2.

Limnological data was collected during five monthly sampling events from May to September in 2012. Total phosphorus concentrations and zooplankton densities were low, while chlorophyll-*a*, phytoplankton, and nitrogen concentrations rose.

Diet and bioenergetic data collected from juvenile sockeye salmon in Afognak Lake revealed that all ages increased in energy density/content throughout the season, but average energy content differed by age and location. Age-0 juveniles had a greater average energy content (but lower condition factor; K) in the spring when they fed more heavily on insects, indicating that K does not apply well to freshwater age-0 juvenile sockeye salmon. The average energy content of age-1 juveniles more closely followed the condition factor, peaking in August and September. On average, individuals collected from the shoals had lower average energy content than individuals collected from mid-lake.

Key words: Afognak Lake, Litnik, mark-recapture, age, outmigration, escapement, bioenergetics, Kodiak Island, *Oncorhynchus nerka*, smolt, sockeye salmon, subsistence harvest, inclined-plane trap, zooplankton

# INTRODUCTION

The Afognak Lake (also referred to as “Litnik” by local residents) watershed is located on the southeast side of Afognak Island, approximately 45 km northwest of the city of Kodiak (Figure 1). Afognak Lake (58°07' N, 152°55' W) lies 21.0 m above sea level, is 8.8 km long, has a maximum width of 0.8 km, and a surface area of 5.3 km<sup>2</sup> (Schrof et al. 2000; White et al. 1990). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, a total volume of 46.0 km<sup>3</sup>, and an estimated lake-water residence time of 0.4 years (Figure 2). Due to its shallow depth, Afognak Lake is easily influenced by wind and ice melt (Cole 1983). Afognak Lake drains in an easterly direction into the 3.2 km long Afognak River, which in turn flows into Afognak Bay. Afognak Bay is part of the Alaska Maritime National Wildlife Refuge and is where most subsistence salmon fishing occurs. The Afognak Native Corporation owns the land surrounding the Afognak Lake watershed down to tidewater.

A counting weir for adult salmon was first established on the Afognak River in 1921 just below the lake outlet and was operated intermittently through 1977. From 1978 to the present, adult escapement data has been collected annually. In 1986, the weir was relocated to its current location, 200 meters upstream of the mouth of Afognak River, and the Alaska Department of Fish and Game (ADF&G) has maintained annual weir counts in conjunction with sockeye salmon *Oncorhynchus nerka* age, length, and sex sampling (Foster et al. 2012b). Catch data have been documented through the ADF&G commercial landing fish ticket system, statewide sport fish surveys, and return of subsistence fishing permits since the late 1970s (Jackson et al. 2012).

In response to declining adult returns, in 1987, ADF&G, in cooperation with Kodiak Regional Aquaculture Association (KRAA), initiated pre-fertilization fisheries and limnological investigations at Afognak Lake (Honnold and Schrof 2001; Schrof et al. 2000; White et al.

1990). Results of these investigations indicated that sockeye salmon production was limited by rearing capacity (White et al. 1990). Nutrient enrichment was recommended and implemented in 1990 to increase primary and secondary production, which was intended to increase sockeye salmon rearing capacity in the lake. The ADF&G and KRAA fertilized Afognak Lake for ten years (1990-2000; White et al. 1990).

Afognak Lake sockeye salmon runs substantially declined beginning in 2001 and escapements from 2002 through 2005 were below the established a sustainable escapement goal (SEG) range of 40,000 to 60,000 sockeye salmon (Baer et al. 2010; Honnold et al. 2007; Jackson et al. 2012; Nemeth et al. 2010). As a result of these poor runs, the commercial sockeye salmon fishery in the South East Afognak Section (which includes all of Afognak Bay and surrounding waters) was closed in 2001 and commercial fishing remained closed until 2005. In 2007, the commercial fishery was again closed, shifting effort to other areas.

In 2004, using new sustainable management policies 5 ACC 39.222 and 5 ACC 39.223, a team of ADF&G biologists re-evaluated the existing Afognak Lake sockeye salmon escapement goal. The team recommended changing the escapement goal from an SEG of 40,000 to 60,000 sockeye salmon to a BEG of 20,000 to 50,000 sockeye salmon (Nelson et al. 2005). The recommendation was based on analysis of a Ricker spawner-recruit model and limnology data, excluding data from years in which the lake was fertilized. In 2007 and 2010, the escapement goal was reevaluated with additional years of data and was recommended to remain unchanged (Honnold et al. 2007; Nemeth et al. 2010).

Escapements during the last decade have been just below (2002 and 2004) to just above (2001, 2003, 2005-2008) the lower end of the biological escapement goal (BEG) range (Appendix A12). The Afognak River sockeye salmon run has only recently (2010–2012) regained sufficient numbers to meet the escapement goal (20,000–50,000) and support commercial harvest.

In addition to sockeye salmon, other fish species in the Afognak Lake drainage include pink salmon *O. gorbuscha*, coho salmon *O. kisutch*, rainbow trout (anadromous and potamodromous) *O. mykiss*, Dolly Varden *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have been observed in the Afognak River on occasion but have not established discernible spawning populations (White et. al 1990).

Sockeye salmon from Afognak Lake are an important target species for salmon fisheries within the Kodiak region. Residents of Port Lions, Ouzinkie, Afognak Village, and Kodiak have traditionally harvested salmon in Afognak Bay for subsistence uses (Figure 1). Afognak Lake experienced poor sockeye salmon runs in 2001 and fishery closures in 2002. Local subsistence users, represented by the Kodiak-Aleutians Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that continued closures of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to small nearby sockeye salmon runs and the Buskin River, constituting an emergency situation. In response to this situation, ADF&G received funding through the Office of Subsistence Management's Fishery Resources Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production in Afognak Lake. An initial feasibility study in 2003 showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark-recapture techniques (Honnold and Schrof 2004).

Continued analysis of Afognak Lake sockeye salmon returns and annual smolt outmigration studies were deemed of high importance for evaluating changes in nutrient food web dynamics (for example, to determine whether the structure of consumer communities has modified nutrient transfer along the food web) and assessing how changes may have affected the growth and production of emigrating juvenile sockeye salmon. Recognizing the importance of continued analysis on Afognak Lake sockeye salmon production, the Office of Subsistence Management approved project funding to ADF&G for an additional four years (2010–2013). This report provides results from the third year (2012) of the four year study.

In addition to the ongoing research, the ADF&G expanded research efforts to investigate the caloric content, or energy budget, of juvenile sockeye salmon as a more robust indicator of condition and health than traditional length and weight data (Finkle 2004). Paired with diet and environmental data, this information can be used with bioenergetics modeling to provide valuable insight into growth and production trends. Such modeling can also identify how juvenile fish adapt to their rearing conditions and exogenous factors such as climate change and volcanic ash from previous eruptions.

The goal of this project is to obtain reliable estimates of smolt and adult production over time for Afognak Lake. Data collected from this project enables researchers to better identify what factors are specifically affecting and controlling sockeye salmon production within the freshwater environment. This will help refine the escapement goal and improve pre-season run forecasts. Better management will allow for maximum sustainable yield and prevent unnecessary restrictions of federal and state subsistence fisheries.

## **PROJECT OBJECTIVES**

### Smolt

1. Estimate the abundance (N), age composition, and average size of outmigrating sockeye salmon smolt within 25% (relative error) of the true value with 95% confidence.
2. Estimate the abundance of outmigrating sockeye salmon smolt using a life-history based model for comparison with the mark-recapture estimate.
3. Estimate the age composition of outmigrating sockeye salmon smolt within  $d=0.05$  (size of the effect) of the true proportion (for each major age group within each stratum) with 95% confidence.
4. Estimate the average length (mm), weight (g), and condition (K) by smolt age group and stratum.

### Adult salmon

5. Enumerate the escapement of adult sockeye salmon returns through the weir and into Afognak Lake.
6. Estimate the age and sex composition of adult sockeye salmon returns where estimates are within  $d=0.07$  of the true proportion (for each age group within each stratum) with 95% confidence.
7. Estimate the average length (mm) of adult sockeye salmon by age and sex.

### Lake Studies and Climate Change

8. Evaluate the condition of juvenile (lake rearing) sockeye salmon relative to diet and energy density.

9. Evaluate the effects of water chemistry, nutrient status, and plankton production of Afognak Lake on smolt production and future adult returns.
10. Assess available historical fisheries and limnological data in relation to climate change effects, upon completion of objectives 1–3.

## **METHODS**

### **SMOLT ASSESSMENT**

#### **Trap Deployment and Assembly**

Two inclined-plane traps (Ginetz 1977; Todd 1994) were placed in Afognak River to capture outmigrating smolt in 2012. The downstream trap was installed approximately 32 m upstream from the adult salmon weir site and was utilized for smolt enumeration and the recapture of marked fish (Figure 3). The upstream trap was installed approximately 1.2 km upstream from the adult salmon weir site and was utilized solely to capture smolt for dye release testing. Capturing smolt at the release site (upstream trap) was intended to reduce the mortality rate encountered during transportation from the capture site (downstream trap) in previous years.

Both traps were positioned towards the middle of the river at each location, where water velocity was great enough to make it difficult for smolt to avoid capture and to capture a representative portion of the outmigrating smolt. A live box (1.2 m x 1.2 m x 0.5 m) was attached to the outlet of each trap, and both trapping devices were connected to cables attached to hand-powered cable “come-along” winches fixed to each stream bank. Both traps were secured to an aluminum pipe frame, which allowed the back end of the trap and live box to be adjusted vertically in response to water level fluctuations.

Smolt trapping was concluded when the number of captured smolt dropped to less than 100 smolt per day for 3 consecutive days. Detailed methods of trap installation, operation, and maintenance are described in the 2012 Afognak Lake Operational Plan (Foster et al. 2012a).

#### **Smolt Capture and Handling**

Smolt live boxes of each trap were checked every 1 to 2 hours during the night (2200 to 0800 hours), depending on smolt abundance. During the day (0801 to 2159 hours), the live boxes were checked every 3 to 4 hours. All smolt were removed from the live boxes with a dip net, counted, and either released downstream of the trap or transferred to an in stream holding box for sampling and marking. The upper trap was only fished until the required number of smolt were captured for mark-recapture (dye release) tests and was not fished until the next dye test trial. Species identification was made by visual examination of external characteristics of juvenile salmonids (Pollard et al. 1997). All data, including mortality counts, were entered on a reporting form each time the trap was checked.

#### **Trap Efficiency and Mark-Recapture Abundance Estimation**

Total smolt abundance was estimated using mark-recapture procedures to estimate trap efficiency within specific recapture periods (weekly strata). Trap efficiency was then used to estimate the number of smolt outmigrating from the watershed during each stratum.

Releases of sockeye salmon smolt marked with Bismarck Brown Y dye were made once per strata (weekly), as well as when changes were made to the trapping system. As in previous years at Afognak Lake, an effort was made to achieve trap efficiencies from 15 to 20% (Baer 2010).

To estimate total smolt abundance of each strata with a 5% probability of exceeding a relative error ( $r$ ) of 25%, 330 to 440 smolt were marked and released for each experiment (Carlson et al. 1998). To estimate mortality associated with the marking, holding, and transport process, 100 marked fish were retained and monitored for four days. Therefore, a sample size of 650 was set as the goal for each experiment to account for any handling or marking mortality and mortality testing. Actual numbers of fish marked, released, and retained for mortality testing varied by release event (Tables 1 and 2). All fish captured and retained for the mark-recapture trial were dyed.

### ***Dyeing Procedure***

Smolt captured for dye release testing at the downstream trap required treatment prior to transportation to the release site (steps 1-2). Smolt were transported in a trailer pulled by an all-terrain vehicle to the release site approximately 1.2 km upstream. Smolt captured at the upstream trap required no transportation and followed steps 3-5.

1. Collected smolt were placed in a 26-gallon lidded cooler, filled with river water and a 0.25% sodium bicarbonate solution to maintain a stable pH. Non-ionized salt was added to the transport water to achieve a 0.75% solution to replicate physiological levels and reduce metabolic stress and electrolyte depletion that can cause post-transport mortality. The transport cooler was continuously supplied with supplemental oxygen at a level of 9 mg/l and within an 80–100% saturation range to maintain conditions similar to ambient river water from which the smolt were collected.
2. Following transport to the release site, smolt were continuously supplied with supplemental oxygen and held for 30 minutes to rest before the dying process.
3. Collected smolt were placed into a 26-gallon lidded cooler (unless following steps 1-2). The 26-gallon cooler was filled with river water and a 0.25% sodium bicarbonate and Bismarck Brown Y dye (30mg/L) solution. The smolt were continuously oxygenated and submerged in the solution for 30 minutes. Dyed smolt that displayed unusual behavior (labored respiration, flared gills, side swimming, etc.) were removed from the experiment and released downstream of the recapture site.
4. The dye solution was replaced with river water and the smolt were held for 30 minutes before release. Roughly 550 of the dyed smolt were randomly selected from the holding box and placed in 5-gallon buckets for release. Timing of the dyeing process was started so dyed smolt were released across the width of the stream between 2100 and 2300 hours.
5. The remaining dyed smolt (roughly 100) were counted and left in the holding box for four days to estimate delayed mortality resulting from the capture and marking process. The proportion of smolt that died during the 4-day holding period was used to estimate the actual number of marked smolt available for recapture in the experiment ( $M_h$ ).  $M_h$  was adjusted by multiplying the delayed mortality ratio (total number of marked and held divided by total number of marked dead) by the number of dyed smolt released.

All dyed smolt recaptured at the downstream trap site were counted and assigned to the strata corresponding to the time period starting the day of their release until the day before the next release and mark-recapture event.

### ***Statistical Formulas***

Trap efficiency  $E_h$  for stratum  $h$  was calculated as

$$E_h = \frac{m_h + 1}{M_h + 1}, \quad (1)$$

where

$m_h$  = number of marked smolt recaptured in stratum  $h$

A modification of the stratified Petersen estimator (Carlson et al. 1998) was used to estimate the number of unmarked smolt  $U_h$  emigrating within each stratum  $h$  as

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1}, \quad (2)$$

where

$u_h$  = number of unmarked smolt recaptured in stratum  $h$ .

Variance of the smolt abundance estimate was estimated as

$$\text{var}(\hat{U}_h) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2(m_h + 2)}. \quad (3)$$

Total abundance of  $U$  of unmarked smolt over all strata was estimated by

$$\hat{U} = \sum_{h=1}^L \hat{U}_h, \quad (4)$$

where  $L$  is the number of strata. Variance for  $\hat{U}$  was estimated by

$$\text{var}(\hat{U}) = \sum_{h=1}^L \text{var}(\hat{U}_h), \quad (5)$$

and 95% confidence intervals were estimated using

$$\hat{U} \pm 1.96\sqrt{\text{var}(\hat{U})}, \quad (6)$$

which assumes that  $\hat{U}$  is approximately normally distributed.

Within each stratum  $h$ , the total population size by age class  $j$  was estimated as

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \quad (7)$$

where  $\hat{\theta}_{jh}$  is the observed proportion of age class  $j$  in stratum  $h$ . Variance of  $\hat{\theta}_{jh}$  was estimated using the standard variance estimate of a population proportion (Thompson 1987). The variance of  $\hat{U}_{jh}$  was then estimated by

$$\text{var}(\hat{U}_{jh}) = \hat{U}_h^2 \text{var}(\hat{\theta}_{jh}) + \hat{U}_h \text{var}(\hat{\theta}_{jh})^2. \quad (8)$$

The total number of emigrating smolt within each age class was estimated by summing the individual strata estimates, and its variance was likewise estimated by summing over individual strata estimates.

### ***Statistical Assumptions***

Statistical assumptions were taken from (Carlson et al. 1998).

- The population was unchanging (i.e., a closed population with no immigration or outmigration),
- all smolt had the same probability of being marked (i.e., trap is not selective and strata are consistent),
- all smolt had the same probability of capture (i.e., marking fish does not affect their behavior or ability to be captured),
- all marked smolt released can be recovered (i.e., marking mortality was accurate),
- all marked smolt were identifiable (i.e., crew well trained and strata are discrete),
- and marks were not lost after marking (i.e., effectively stained).

### **Life History-Based Abundance Estimation**

In addition to mark-recapture abundance estimates, the predicted number of smolts expected to outmigrate in 2012 was estimated based on a life history model (Table 3). The history-based estimates utilized sex composition data from parental spawning escapements in 2009 (51% females) and 2010 (61% females), average egg deposition based on the average fecundity assessment of females used in egg-takes by Pillar Creek Hatchery crews in 2009 (2,591 per female) and 2010 (2,539 eggs per female), a 7% egg-to-fry survival (Bradford 1995; Drucker 1970; Koenings and Kyle 1997), a 21% fry-to-smolt survival (Koenings and Kyle 1997) from rates reported from other clear water systems, and a smolt age composition of 74% freshwater-age-1 and 26% freshwater-age-2 based on the smolt age composition from 2012. Annual differences between life-history based and mark-recapture estimates were regressed for comparison.

### **Age, Weight, and Length Sampling**

To ensure proportional abundance sampling, approximately 2% of the daily sockeye salmon smolt catch was sampled to obtain age, weight, and length (AWL) data. For every 100 sockeye salmon smolt counted out of the trap, the field crew retained two smolt for AWL sampling the following morning. Smolt were collected throughout the night and held in the instream live box. The following day, all smolt from the live box were anesthetized using tricaine methanesulfonate (MS-222) prior to being sampled. After being sampled, all smolt were held in aerated buckets of water until they recovered from the anesthetic, and subsequently released downstream from the trap.

Fork length was recorded to the nearest 1 mm and weight to the nearest 0.1 g. Scales were removed from the preferred area of each fish following procedures outlined by the International North Pacific Fisheries Commission (INPFC 1963) and mounted on a microscope slide for age determination.

Age was estimated from scales viewed with a microfiche reader at 60X magnification and recorded in European notation (Koo 1962) following the criteria established by Mosher (1968). In addition, the overall health or condition factor of each sampled smolt was assessed by calculating its body condition factor  $K$  (Bagenal and Tesch 1978) as

$$K = \frac{W}{L^3} 10^5 \quad (9)$$

where

W = weight and L = length.

## **ADULT SALMON ASSESSMENT**

### **Weir Installation and Adult Salmon Enumeration**

A 27 m weir was installed near the terminus of the Afognak River on 16 May, 2012. The weir was constructed perpendicular to the stream flow and consisted of 10 wooden tripods (each tripod consisting of three 4" x 4" x 8' spruce timbers and 2" x 6" x 6' horizontal cat-walk supports), 33 aluminum pipes (2" x 10'), 44 picketed aluminum panels (1" aluminum pipe with 1" spacing totaling 30" x 6'), and 2 framed panel gates (Figure 4). All materials were secured with sand bags and lashed together to create a fish tight structure that conformed to the stream substrate.

Two counting gates were placed between panels in the two deepest channels of the river enabling fish to be counted as they pass through the weir. A white flash panel was placed on the substrate beneath each gate to enhance visibility and speciation. Fish were counted by field technicians using hand tally denominators as fish migrated upstream through the gates. The counting gates remained closed until staff were present to count fish through the weir for escapement enumeration or when fish were being collected into the live trap for age, sex, and length sampling (Foster et al. 2012b).

### **Age, Sex, and Length Sampling**

An upstream "Scott live trap" (Figure 4; local name for a modified trap capable of capturing steelhead) was installed in front of the near shore (east bank) gate, which acted as a sampling trap as well as a downstream steelhead trap. The trap consisted of 6 weir panels placed horizontally in the river in the form of a diamond (Thomsen 2012).

Adult sockeye salmon were sampled at the weir site throughout the adult escapement. Details and procedures for adult sampling are outlined in the Kodiak Management Area sockeye salmon catch and escapement sampling operational plan, 2012 (Foster et al. 2012b). All scales, when possible, were collected from the preferred area of each fish (INPFC 1963). Scales were mounted on scale "gum" cards and returned to the Kodiak ADF&G office where impressions were made on cellulose acetate (Clutter and Whitesel 1956). Fish ages were determined by examining scale impressions for annual growth increments using a microfiche reader fitted with a 48X lens following designation criteria established by Mosher (1968). Ages were recorded using European notation (Koo 1962), where a decimal separates the number of winters spent in fresh water (after emergence) from the number of winters spent in salt water (e.g., 2.3). The total age of the fish includes an additional year representing the time between egg deposition and emergence of fry.

Length measurements were taken from mid eye to tail fork to nearest 1 mm and sex was determined from external morphological characteristics.

Age and sex composition of the upstream migrating adult sockeye salmon were estimated daily as a group of proportions ( $p_{ij}$ ) characterizing a multinomial distribution:  $\hat{p}_{ij} = n_{ij} / n$ , where  $n$  = the number in the sample and  $n_{ij}$  = the number in the sample of age  $i$  and sex  $j$ . On days where escapement occurred but no samples were collected, proportions were estimated by linear interpolation between sampling events. The sample size was selected so that the proportion of each major age group (by stratum) was estimated within at least  $\alpha=0.07$  of its true value 95% of the time (Thompson 1987). Standard error of the age proportions was calculated as the square root of estimated variance of a proportion (Thompson 1987). The five sampling strata were stratum 1 (8 May–1 June), stratum 2 (2 June–7 June), stratum 3 (8 June–15 June), stratum 4 (16 June–23 June), and stratum 5 (24 June–28 June). Average length (unweighted) was calculated by age and sex.

## **LIMNOLOGICAL ASSESSMENT**

### **Lake Sampling Protocol**

Five limnological surveys of Afognak Lake were conducted at approximately four week intervals from May to September, 2012. Two stations, marked with anchored mooring buoys and located with Global Positioning System equipment, were sampled from a float plane during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. Data and water samples were returned to the ADF&G Near Island Laboratory (Kodiak, AK) for analyses.

### **Temperature, Dissolved Oxygen, Light, Water Clarity and Euphotic Volume**

Water temperature (°C) and dissolved oxygen (mg L<sup>-1</sup>) levels were measured with a YSI® meter. Surface temperature readings were calibrated against a hand-held mercury thermometer. Temperature and dissolved oxygen readings were recorded at half-meter intervals to a depth of 5 m and then at one-meter depth intervals to the lake bottom. Results were categorized into spring (May–June), summer (July–August), and fall (September–October) sampling periods. In addition, four Hobo® water temperature data loggers were deployed in Afognak Lake and recorded water temperatures every hour at depths of 1, 5, 10, and 13 m continuously from 14 May to 5 October.

Water transparency was measured at each station using a Secchi disc as described in Thomsen (2008). Measurements of light in the visible spectrum range (400–700 nanometers), known as photosynthetic active radiation (PAR), were obtained with Li-Cor® Spherical Quantum Sensors every hour from depths of 1 m and 10 m and recorded on a Li-Cor® data logger from 21 May to 30 May. PAR measurements were also obtained with a Li-Cor® (Li-250) submersible photometer at the lake sampling stations during the monthly sampling schedule. Readings were taken above the water surface, just below the water's surface (subsurface), and at half-meter intervals below the water surface until reaching a depth of 5 m and then at one-meter intervals to the lake bottom or to a depth at which the reading was (no more than) 1% of the subsurface reading.

Measurements were adjusted by linear regression to the Beer-Lambert equation (Wetzel 1983) to estimate an integrated vertical extinction coefficient ( $K_d \text{ m}^{-1}$ ) for PAR within the euphotic zone, the layer of water from the surface down to 1% of subsurface PAR as

$$K_d \text{ m}^{-1} = (1/z) \ln (I_z / I_o), \quad (10)$$

where

$I_o$  = light intensity just below the water surface, and

$I_z$  = light intensity at water depth  $z$  in meters.

Lake primary production potential for rearing juvenile sockeye salmon was assessed through a euphotic volume calculation as the product of the average euphotic zone depth for the five monthly sampling periods and lake surface area (Koenings and Burkett 1987).

### **General Water Chemistry, Phytoplankton and Nutrients**

During each survey, water samples were collected at a depth of 1 m below the water's surface using a 4.0 L Van Dorn sampler. Each water sample was emptied into a pre-cleaned polyethylene carboy, which was kept cool and dark, until refrigerated at the Kodiak Island laboratory. Water samples were processed or frozen within 3 days of arriving at the laboratory. Lake water from the carboy was transferred into a 500 ml bottle, refrigerated, and analyzed for alkalinity and pH. A 250 ml bottle was filled with unfiltered water from the carboy, frozen, and later analyzed for total Kjeldahl nitrogen (TKN), total phosphorus (TP), and reactive silicon (Si). A total of 2.0 L of water was filtered using the following two different methods for assessing different water quality parameters. One 1.0 L of water was filtered through a rinsed 4.25 cm diameter Whatman® GF/F cellulose fiber filter under 15 psi vacuum pressure for filtrate collection. The filtrate was then analyzed for total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), nitrate + nitrite ( $\text{NO}_3^- + \text{NO}_2^-$ ), and ammonia ( $\text{NH}_4^+$ ). The second 1.0 L of lake water was filtered through another Whatman fiber filter pad with the addition of approximately 5 ml of magnesium carbonate ( $\text{MgCO}_3$ ) added to the final 50 ml of water near the end of the filtration process to act as a preservative. The filtrate was discarded and the fiber filter was retained and frozen on a petri dish for chlorophyll-*a* (chl-*a*) and phaeophytin (pheo-*a*) analysis.

The pH of water samples from samples collected at 1 m was measured in situ with a YSI pH meter. The pH of water samples collected at depth was measured with an Oakton pHTestr 30® meter. Alkalinity ( $\text{mg L}^{-1}$  as  $\text{CaCO}_3$ ) was determined from 100 ml of unfiltered water titrated with 0.02 N  $\text{H}_2\text{SO}_4$  to a pH of 4.5.

Ammonia,  $\text{NO}_3^- + \text{NO}_2^-$ , and Si were analyzed using a SEAL Analytical AA3 segmented flow autoanalyzer by methods described in the manufacture's chemistry protocols. TP, TFP, and FRP was analyzed using methods described in Koenings et al. (1987) and Thomsen (2008). TKN was determined at the University of Georgia Feed and Environmental Water Laboratory using the 4500-N D conductimetric method of inorganic nitrogen determination.

Total nitrogen (TN), the sum of TKN and  $\text{NO}_3^- + \text{NO}_2^-$ , and the ratio of TN to TP were calculated for each sample. Chlorophyll *a* is the primary photosynthetic pigment in plants and is commonly used as an index of phytoplankton abundance. Samples of chl *a* were prepared for analysis by separately grinding each frozen filter containing the filtrate in 90% buffered acetone using a mortar and pestle, and then refrigerating the resulting slurry from each sample in separate

15-ml glass centrifuge tubes for 2 to 3 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone. The extracts were analyzed with a SG5 (spectrophotometer) using methods described in Thomsen (2008) and Koenings et al. (1987). Concentrations of pheo *a*, a common degradation product of chl *a*, were simultaneously estimated during the spectrophotometer analysis of chl *a*. The ratio of chl *a* to pheo *a* was calculated to provide an indicator of phytoplankton physiological condition.

## **Zooplankton**

Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153  $\mu\text{m}$  mesh. The net was pulled manually at a constant speed ( $\sim 0.5 \text{ m sec}^{-1}$ ) from approximately 1 m off the lake bottom to the surface. The contents from each tow were emptied into a 125 ml polyethylene bottle and preserved in 10% buffered formalin. Cladocerans and copepods were identified to genus using taxonomic keys in Edmondson (1959), Thorp and Covich (2001), and Wetzel (1983). Zooplankton lengths were measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Zooplankton were grouped at the genus level and measured to the nearest 0.01 mm. The standard deviation (SD) of the lengths (L) of up to 15 individuals was estimated. This value was then used to estimate the appropriate sample size (N) by applying it to a *t*-test (*t*) with a 0.05 significance level and relative to 10% variation from the mean measured length calculated as

$$N=[(t \times \text{SD})/(0.1 \times L)]^2. \quad (11)$$

Biomass was estimated from species-specific linear regression equations of length and dry weight derived by Koenings et al. (1987). For each survey, average density and biomass from the two stations were calculated for each genera.

## **Phytoplankton**

For phytoplankton analysis, 4.0 ml of Lugol's acetate was added to 200 ml of water withdrawn from the contents of the 1 m water sample carboy. Samples were sent to BSA Environmental Services Incorporated (Beachwood, Ohio) for analysis.

## **JUVENILE (LAKE REARING) ASSESSMENT**

### **Juvenile Collection**

A total of five shoal and five mid-lake locations were selected to obtain representative samples of juvenile sockeye salmon rearing in Afognak Lake (Figure 2). The ten sites were sampled on a biweekly basis from June through September in an effort to capture representative fry (freshwater-age-0) and fingerling (freshwater-age-1) juvenile sockeye salmon. A 50 m tapered beach seine with 4 mm stretched mesh was utilized for the collection of fish on the five shoal sites. A small mesh pelagic trawl, a small purse seine (30 m), or a 3.5 m cast net were used on the mid water sites. All captured fish were identified and enumerated. Juvenile sockeye salmon were separated into three size groups ( $<45 \text{ mm}$ ,  $46 \text{ to } 65 \text{ mm}$ , and  $\geq 65 \text{ mm}$ ) to ensure proportional representation of each age group. When available, a minimum of five juvenile sockeye salmon representing each size and age group were retained for stomach content and bioenergetic analysis. The retained juvenile samples were separated by sample location, stored in Whirl-Pak® bags with lake water, and transported to the field lab where individual AWL data was collected as described by Foster et al. (2012a).

Each sample was individually stored in Whirl-Pak® bags and frozen in the field before being transported via aircraft to the Kodiak laboratory for further analysis.

### **Diet and Bioenergetic Analysis**

Ages were assigned to all of the collected samples using previously described methods. When five or more samples were available from each sample location, date, and age group, three random samples were selected exclusively for stomach content analysis leaving two samples for calorimetric assessment. The stomachs of the selected fish were removed and the contents examined. The percent “fullness” (0–100%) was assessed and the percentage of zooplankton and invertebrates within the stomach was determined. When possible the zooplankton and invertebrates were identified by genera through the same methods as described in the limnological assessment and through additional taxonomic key identification (McCafferty 1983; Pennak 1989).

The remaining two samples per location, time, and age (or as many were available) were stored at or below -20°C prior to shipping samples to the ADF&G laboratory in Soldotna for further bioenergetic processing. The energy density or calories per gram (cal/g) of each sockeye salmon sample was determined within a precision of 0.1% through the use of a Parr model 1266 Isoperibol microbomb calorimeter as per the manufactures specifications (Parr Instrument Company 1999).

## **RESULTS**

### **SMOLT ASSESSMENT**

#### **Smolt Capture**

The downstream inclined-plane trap was fished continuously from 8 May until it was removed for the season on 28 June, 2012 (Table 1). A total of 22,092 sockeye salmon smolt were captured from 8 May to 28 June (Table 2; Figures 5 and 6).

#### **Trap Efficiency and Mark-Recapture Abundance Estimation**

Daily catches of sockeye smolt in the beginning of the outmigration did not provide adequate trap catches for mark-recapture testing (8 May through 25 May; Table 2). As a result, the trap efficiency estimated for 28 May was applied to the first stratum. Standard mark-recapture trap efficiency methods were used to generate the total outmigration for the remaining four strata. The five trap efficiency tests ranged from 22.7% in stratum 3 (8 June to 15 June) to 12.8% in stratum 4 (16 June to 23 June; Table 2; Figure 6). Mean estimated trap efficiency for the total outmigration was 17.7%. Peak smolt outmigration occurred in stratum 3 (8 June to 15 June) with the outmigration tapering off in stratum 4. The estimated total sockeye salmon smolt outmigration from Afognak Lake in 2012 was 127,862 with 95% CI (98,551–157,173; Table 1). This is well below the ten-year mean outmigration estimate of 373,850 fish and the five-year mean outmigration estimate of 320,893 fish (Appendices A1 and A2).

#### **Life History-Based Abundance Estimation**

Using the life history-based abundance method and the previous assumptions identified, the 2009 escapement of 31,358 adults (brood year 2009) could produce 155,592 freshwater-age-2 smolt. The 2010 escapement of 52,255 adults (brood year 2010) could produce 878,368 freshwater-

age-1 smolt (Table 3; Figure 7). Combining these two age classes resulted in an outmigration of 1,033,961 smolt from Afognak Lake in spring 2012.

### **Age, Weight, Length, and Condition Factor**

AWL data were obtained from 508 smolt collected proportionally throughout the trapping period (Table 2). Summing smolt abundance estimates by age class for all five mark-recapture strata resulted in 99,541 (77.9%) freshwater-age-1 and 28,321 (22.1 %) freshwater-age-2 smolt outmigrating to the ocean (Table 4; Figure 8).

Sampled freshwater-age-1 smolt had a mean weight of 3.1 g, a mean length of 73 mm, and a mean K of 0.81. Sampled freshwater-age-2 smolt had a mean weight of 3.9 g, a mean length of 79 mm, and a mean K of 0.78. (Table 5).

## **ADULT ASSESSMENT**

### **Enumeration**

The adult weir was installed on 16 May, with the first salmon passing through the counting gates on 23 May. Adult salmon were enumerated on a daily basis until 25 August when the weir was removed. A post-weir estimate of 100 sockeye, 20,000 pink, and 2,000 coho salmon was added to the escapement, using crew observations, after removal of the weir. In 2012, 41,553 sockeye, 71,928 pink, 5,701 coho, and 5 chum salmon escaped into the Afognak system from 16 May to 25 August (Table 6; Figure 9; Fuerst 2012). Additionally, 91 seaward-migrating steelhead were enumerated and passed downstream through the weir. Sockeye salmon escapement peaked from 7 June through 13 June when 13,483 fish were enumerated (Table 7).

### **Age, Sex, and Length Data**

A total of 858 adult sockeye salmon were sampled from 3 June through 11 August, resulting in a total of 767 samples where age could be determined from the scales. Distribution of the samples was as follows: stratum 1 (17 May–6 June; n=53), stratum 2 (7 June–13 June; n=253), stratum 3 (14 June–20 June; n=175), stratum 4 (21 June–18 July; n=227), and stratum 5 (19 July–29 August; n=59). The goal of estimating age composition of the escapement within  $d=0.07$  (95%) confidence was achieved for all ages within each strata (Table 7).

The majority (56.7%) of the escapement was comprised of age-1.3 fish, 15.7% were age-1.2 fish, 14.0% were age-2.2 fish, and 10.4% were age 2.3 sockeye salmon (Table 7). The majority of age-1.2 and age-1.3 fish escaped during June. The estimated sex composition of the total escapement was 58.8% female and 41.2% male. Roughly 65% of the age-1.3 fish sampled were female, 57% of the age-1.2 fish sampled were female, and 57% of the age-2.2 fish sampled were female. Overall average length was 510 mm for all fish, 539 mm for age-1.3 fish, and 471 mm for age-1.2 fish (Table 8).

## **LIMNOLOGICAL ASSESSMENT**

### **Temperature, Dissolved Oxygen, Light, Water Clarity, and Euphotic Volume**

Monthly water temperatures at station 1 taken during limnology sampling ranged from 6.0°C near the lake bottom on 24 May to 14.7°C between 1.5 and 12.0 m on 17 August (Figure 10). Seasonal mean water temperatures at 1 m and near the bottom were generally below the historical average (1989-2011; Appendix A5).

In 2012, the data logger at 1 m (Station 2) was operated continuously from 14 May to 5 October, recording temperature every hour. For comparison with monthly limnology sampling averages, mean surface (1 m) temperatures were 9.8°C in the spring, 14.6°C in the summer, and 11.0°C in the fall (Table 9; spring 10.2°C, summer 14.4°C, fall 11.8°C; Appendix A5). The temperature logger recorded a maximum of 17.3°C in July, a minimum of 5.7°C in May, a mean daily variation of 0.7°C, a maximum daily variation of 2.9°C, and a overall mean of 12.6°C.

Afognak Lake was stratified from May through July with turnover occurring in August (Figure 10). Monthly dissolved oxygen (DO) concentrations at station 1 taken during limnology sampling ranged from 12.6 mg L<sup>-1</sup> at the surface in the spring to 9.5 mg L<sup>-1</sup> near the lake bottom in the summer (Appendix A6). Mean vertical light extinction coefficient was -0.45 m<sup>-1</sup>, mean euphotic zone depth was 9.81 m, and mean Secchi disk reading was 4.90 meters (Appendix A6). Estimated euphotic volume for Afognak Lake was 51.99x10<sup>6</sup> m<sup>3</sup> (Appendix A7). Using the EV model and 800–900 spawners per EV unit resulted in a spawning capacity estimate of 41,594 to 46,794 adults (Koenings and Kyle 1997).

Euphotic zone depth (EZD) values recorded in 2012 indicated that, on average, the first 10 m of the water column at the sampling stations were photosynthetically active (Appendix A7). Historic mean EZD values were comparable, with 9 m of the water column being photosynthetically active (1987-2011; Appendix A7).

### **General Water Chemistry and Nutrients**

Afognak Lake mean pH was 7.45 and ranged from 7.27 in May to 7.68 in July (Station 1; Table 10; Appendix A8). Mean alkalinity level was 11.1 mg L<sup>-1</sup> and ranged from 10.0 mg L<sup>-1</sup> in July to 12.0 mg L<sup>-1</sup> in August and September (Table 10). Mean chl-*a* concentration was 1.74 µg L<sup>-1</sup> and ranged from 1.12 µg L<sup>-1</sup> in May and June to 2.31 µg L<sup>-1</sup> in August (Table 10). Mean pheo-*a* concentration was 0.12 µg L<sup>-1</sup> and ranged from 0.05 µg L<sup>-1</sup> in September to 0.22 µg L<sup>-1</sup> in July. Mean reactive silicon concentration was 2,805.6 µg L<sup>-1</sup> and ranged from 2,546.8 µg L<sup>-1</sup> in September to 3,065.3 µg L<sup>-1</sup> in May (Table 11).

Three different measures of seasonal phosphorus were made (Table 11; Appendix A9). Mean TP concentration was 3.8 µg L<sup>-1</sup> and ranged from 3.5 µg L<sup>-1</sup> in September to 4.0 µg L<sup>-1</sup> in July (Table 11). Mean TFP concentration was 1.7 µg L<sup>-1</sup> and ranged from 1.5 µg L<sup>-1</sup> in June to 2.0 µg L<sup>-1</sup> in May. Mean FRP concentration was 0.8 µg L<sup>-1</sup> and ranged from 0.4 µg L<sup>-1</sup> in August to 1.1 µg L<sup>-1</sup> in June.

Three different measures of seasonal nitrogen were made (Table 11; Appendix A9). Mean TKN concentration was 298.7 µg L<sup>-1</sup> and ranged from 235.2 µg L<sup>-1</sup> in August to 395.0 µg L<sup>-1</sup> in May. Mean NH<sub>4+</sub> concentration was 5.8 µg L<sup>-1</sup> and ranged from 1.5 µg L<sup>-1</sup> in July to 10.6 µg L<sup>-1</sup> in August. Mean NO<sub>2</sub> + NO<sub>3</sub> concentration was 33.5 µg L<sup>-1</sup> and ranged from 1.9 µg L<sup>-1</sup> in August to 86.9 µg L<sup>-1</sup> in May. Mean TN concentration was 332.3 µg L<sup>-1</sup> and ranged from 237.1 to 481.9 µg L<sup>-1</sup>. The overall mean TN to TP ratio, by weight, was 195.4:1 and ranged from 141.9:1 in August to 280.8:1 in May.

### **Zooplankton**

In 2012, overall (stations 1 and 2 averaged) mean zooplankton density was 85,695 no./m<sup>2</sup> (Table 12). All zooplankton were cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were more abundant (64.2% of

mean density) than copepods (35.8%). Among the cladocerans, the two most abundant groups were *Bosmina* (85.0% of cladocerans; 54.6% of total density) and a pooled category called “other cladocerans” (8.5% of cladocerans; 4.6% of total), which consisted of various unidentified immature cladocerans. Other observed cladoceran genera were *Daphnia* (4.6%; 2.9% of total) and *Holopedium* (1.9%; 1.2% of total). Among the copepods, the two most abundant groups were the *Epischura* (52.7% of copepods; 18.9% of total) and the pooled category of “other copepods” (34.4% of copepods; 12.3% of total) which was made up mostly of the genus *Harpacticus* and various unidentified nauplii (larvae) or immature copepods. The other copepod genera included *Cyclops*, usually an important component of the zooplankton community in sockeye salmon rearing lakes (9.5% of copepods; 3.4% of total), and *Diaptomus* (3.5% of copepods; 1.2% of total).

In 2012, the seasonal mean weighted zooplankton biomass was  $104.7 \text{ mg m}^{-2}$ , and was mostly comprised (62.3% of mean total biomass) of copepods (Table 12). The copepod genus *Epischura* (53.2%) represented most of the biomass, followed by the cladoceran genus *Bosmina* (34.5%). The remaining biomass was composed of *Holopedium* (2.2%), *Daphnia* (3.8%), *Cyclops* (3.9%), *Diaptomus* (2.4%), and “other copepods and cladocerans,” which consisted of larvae too small to weigh.

The copepod *Epischura* was the largest zooplankton genus/species measured, with a weighted mean length of 0.94 mm (Table 12; Appendices A10 and A11). Mean lengths of the remaining zooplankton measured, in decreasing size, were 0.81 mm for the copepod *Diaptomus*, 0.64 mm for the copepod *Cyclops*, 0.61 mm for the cladoceran *Daphnia*, 0.51 mm for the cladoceran *Holopedium*, and 0.29 mm for the cladoceran *Bosmina*. All mean weighted lengths include ovigerous individuals.

For historical comparison, using only the predominant crustaceans at station one, the ten-year (2002–2011) average weighted mean zooplankton density was  $96,509 \text{ no/m}^2$  (Post fertilization; Appendices A10 and A11). This compares with the 2012 average weighted mean zooplankton density at station one of  $89,980 \text{ no/m}^2$ . The ten-year average zooplankton biomass was  $123 \text{ animals mg m}^{-2}$ . This compares with the 2012 mean total zooplankton biomass at station one of  $143 \text{ mg m}^{-2}$ .

## Phytoplankton

In 2012, the seasonal mean phytoplankton biomass was  $1,143.1 \text{ mg m}^{-3}$ . Phytoplankton species composition was predominately composed of Bacillariophyta ( $728.4 \text{ mg m}^{-3}$ ), Pyrrophyta ( $209.9 \text{ mg m}^{-3}$ ), and Cryptophyta ( $134.4 \text{ mg m}^{-3}$ ; Table 13). Phytoplankton species composition for 2011 was not analyzed in time for inclusion in the 2011 report and therefore is included in this report. In 2011, the seasonal mean phytoplankton biomass was  $654.8 \text{ mg m}^{-3}$ . In 2011, phytoplankton species composition was predominately composed of Chrysophyta ( $267.5 \text{ mg m}^{-3}$ ), Bacillariophyta ( $228.8 \text{ mg m}^{-3}$ ), and Pyrrophyta ( $42.1 \text{ mg m}^{-3}$ ; Table 14).

## JUVENILE (LAKE REARING) ASSESSMENT

### Juvenile Collection

A total of 368 (367 usable) lake rearing juvenile sockeye salmon were captured in Afognak Lake from May to October, 2012 (Table 15). The five shoal collection sites (Figure 2; stations 1–5) provided a total of 274 specimens while 93 juvenile sockeye salmon were collected from the mid lake collection sites (Figure 2; stations 7 and 8). Of the shoal samples, 206 were freshwater-age-

0, 58 were freshwater-age-1, and 10 were freshwater-age-2. Of the mid lake samples, 84 were freshwater-age-0 and 9 were freshwater-age-1.

### **Diet and Bioenergetic Analysis**

Stomach contents of 259 lake rearing juveniles were analyzed; of those, 209 were freshwater-age-0, 45 were freshwater-age-1, and 5 were freshwater-age-2 fish (Table 16; Figure 11). Average monthly stomach fullness remained fairly steady for freshwater-age-0 fish (62%), with a slight peak in August. There was a slight difference in stomach fullness for freshwater-age-0 juveniles, with shoal samples having fuller stomachs (66.4%) than mid-lakes samples (59.0%). Average monthly stomach fullness varied for freshwater-age-1 juveniles (62%), with the lowest values in May (33.1%) and October (37.5%), and peaking in June (93.5%). Stomach fullness for freshwater-age-1 juveniles remained fairly constant between sample locations. Stomach fullness was only available for May and June for freshwater-age-2 fish, which remained consistently low (30%).

Lake rearing juveniles (102) were examined for calorimetric analysis; of those, 76 were freshwater-age-0, 21 were freshwater-age-1, and 5 were freshwater-age-2 (Table 16; Figures 12 and 13). Of the freshwater-age-0 fish, 53 were from shoal sites and 25 were from mid lake sites. Of the freshwater-age-1 fish, 19 were from shoal sites and 2 were from mid lake sites. All freshwater-age-2 individuals were from shoal sites. Freshwater-age-0 juveniles from the shoals averaged 5,744 cal/g and those from mid lake averaged 5,612 cal/g. Freshwater-age-1 juveniles from the shoals averaged 5,372 cal/g and those from mid lake averaged 5,759 cal/g. Freshwater-age-2 juveniles from the shoals averaged 4,732 cal/g. The average energy content (cal/g) increased over time for freshwater-age-1 fish, but for freshwater-age-0 fish, energy content declined after May then remained fairly steady throughout the summer. Freshwater-age-1 juveniles had the greatest average cal/g in August. In contrast, the condition of lake rearing juvenile sockeye salmon increased steadily throughout the season for all age classes (Figures 12–14).

For freshwater-age-0 fish, zooplankton comprised the majority of juvenile stomach content (57.4%), although considerable differences were found in the proportion of zooplankton by sample date and site location (Table 16; Figures 15 and 16). Freshwater-age-0 fish collected from mid-lake had stomach contents mainly composed of zooplankton (74.4%) while shoal-caught freshwater-age-0 fish selected insects (64.8%). For shoal sites, the proportion of insects within the diet increased over time, until October when zooplankton composed a greater portion of the diet. For mid-lake sites, zooplankton composed the majority of the diet throughout the season.

For freshwater-age-1 fish, insects composed a greater portion of the diet (57.2%), although considerable differences were found by sample date and site location (Table 16; Figures 17 and 18). Mean stomach content composed of zooplankton from freshwater-age-1 juveniles collected from mid-lake sites (64.6%), while insects composed the majority of stomach content for freshwater-age-1 juveniles collected from shoal sites (78.0%). For shoal sites, the proportion of insects within the diet increased over time. For mid-lake sites, the proportion of insects within the diet increased over time. Of the five freshwater-age-2 juveniles captured, all were captured in mid-lake sites, with the majority of their diet consisting of insects (larger prey; 81.0%).

## DISCUSSION

### SMOLT ASSESSMENT

This was the second year two-site mark-recapture methods were employed in Afognak Lake (Thomsen 2012). The previous eight years employed one-site mark-recapture methods (Baer 2011). Despite changes in field personnel, project biologists, trapping methods, and varying environmental conditions, the annual mean trap efficiency (2003 to 2012; 16.8%) has been within the target range of 15% to 20% and ranged between 11.4% to 19.9% annually (Appendix A1).

The 2012 sockeye salmon smolt estimate from Afognak Lake (127,862) was the lowest recorded since the mark-recapture project was initiated in 2003. The 2012 outmigration estimate was 40% of the five-year mean (320,893) and 34% of the ten-year mean (373,850; Appendices A1 and A2).

The five-year (2007–2011) average age composition of sockeye salmon smolt was composed of 74.5% freshwater-age-1, 25.5% freshwater-age-2, and 0.1% freshwater-age-3 smolt (Appendix A2). The ten-year (2003–2011) average age composition of sockeye salmon smolt is composed of 77.0% freshwater-age-1, 23.0% freshwater-age-2, and 0.0% freshwater-age-3.

For freshwater-age-1 smolt, the five-year mean (2007–2011) weight was 3.0 g, length was 73 mm, and K was 0.77. For freshwater-age-2 smolt, the five-year mean weight was 4.1 g, length was 82 mm, and K was 0.74 (Appendix A3). For freshwater-age-1 smolt, the ten-year mean (2002–2011) weight was 3.3 g, length was 74 mm, and K was 0.79. For freshwater-age-2 smolt, the ten-year mean weight was 4.0 g, length was 81 mm, and K was 0.75.

Life history-based population estimates were also calculated for comparison to the mark-recapture estimates. In 2012, the life history-based estimate was 88% greater than the mark-recapture estimate (Table 3; Figure 7; Appendices A1 and A2). During the last 10 years (2003–2012), life-history-based estimates have averaged 27% greater than mark-recapture estimates (Figure 7). Life history-based abundance estimates have been greater than mark-recapture abundance estimates in seven years (2003, 2006 to 2008, and 2010 to 2012) and less than mark-recapture abundance estimates in three years (2004, 2005, and 2009).

Although differences between life history-based and mark-recapture estimates are greater for freshwater-age-2 smolt (39%; 2003–2012), freshwater-age-1 smolt comprise, on average, 79% of the outmigration (24%; 2003–2012). On average, the life history-based estimate has been higher by 86,200 for age.1 smolt and 45,697 for freshwater-age-2 smolt when compared to the mark-recapture estimate. However, the 2012 estimates were different by 778,827 for age.1 smolt and 127,271 for freshwater-age-2 smolt.

The large difference between population estimates in 2012 may indicate that juveniles are holding over in the lake, potentially indicating a large outmigration of freshwater-age-2 smolt in 2013. Although it is unlikely that all 778,827 freshwater-age-1 juveniles (based on the life history estimate) will outmigrate as freshwater-age-2 smolt, increased capture rates in the lake were evident in 2012 (compared to 2011). In contrast, freshwater-age-1 smolt from the 2012 outmigration (freshwater-age-0 juveniles in 2011) had lower May energy content than freshwater-age-0 fish residing in the lake in 2010 and 2012, possibly indicating poor survival

(Appendix A19). Additionally, very few freshwater-age-0 juveniles were captured in 2011 (none at shoal sites), and none were captured in the 30–40 mm range as in 2010 and 2012.

The life history estimate applies egg to fry and fry to smolt values taken from Koenings and Kyle (1997). Koenings and Kyle's values were calculated from a variety of large, very productive lakes, and do not closely approximate those found in Afognak Lake.

## **JUVENILE LAKE ASSESSMENT**

Collection of juvenile sockeye salmon from shoal sites were more successful this year. Mid-lake juvenile sockeye salmon samples remained difficult to obtain until capture methods and trawling techniques were modified which resulted in consistent mid-lake capture after 30 June. Although juvenile sockeye salmon samples were obtained most months in 2012, prior years (2009–2011) have not met with much success therefore comparison to data from previous years is limited. Generally, individuals collected from mid-lake sites had greater energy content (cal/g) than those collected from the shoals (all years; Appendices A16–A18). The greatest mean energy content was observed in 2010, and the lowest mean energy content was observed in 2011. However, these generalizations could be the result of small sample sizes.

Seasonal fluctuations in energy content closely match seasonal fluctuations in condition factor for freshwater-age-1 juvenile sockeye salmon (Figures 14 and 19). The energy content of freshwater-age-0 juveniles did not exhibit a similar trend with condition factor (Figures 14 and 20). The disparity between energy content and condition factor for freshwater-age-0 juveniles is most pronounced in May, when freshwater-age-0 juveniles are predominately feeding on insects. Finkle (2004) found that in Black Lake juvenile sockeye salmon feeding on chironomid larvae (insect larvae) had higher energy content than those eating zooplankton. Considering the findings above, using energy content seems to be a better measure of freshwater-age-0 juvenile fitness, rather than condition, because condition, a ratio of length to weight doesn't account for the actual energy content. Chironomids in the pupae stage were the dominant insects observed in juvenile diets and *Bosmina* were the dominant zooplankton observed in juvenile diets (N. Richardson, ADF&G, unpublished data). Juvenile sockeye salmon captured at shoal sites had more insects in their diet compared to fish captured at mid-lake sites, which had a greater percentage of zooplankton in their diet. In view of the limited number of samples obtained during the months of May and September, continued collection of juveniles in Afognak Lake is needed to better determine trends in both diet and energy content of Afognak juveniles.

Large numbers of juvenile coho and three spine stickleback have been captured at shoal sites in Afognak Lake. Competition for prey from juvenile coho salmon and three spine stickleback has been well documented in Alaska (Parr 1972; Hale 1981). Competition by three spine sticklebacks is currently being studied as a graduate project in Afognak Lake (N. Richardson, ADF&G, unpublished data). Ruggerone and Rogers (1992) also found a significant amount of predation (to 59% of sockeye fry) by juvenile coho salmon on sockeye salmon fry in Chignik Lake. Competition and predation by juvenile coho should be conducted in the future to document possible interspecies interactions.

## **LIMNOLOGICAL ASSESSMENT**

Seasonal means of lake physical properties (temperature, DO, light, and water clarity) in 2012 were consistent with measurements taken in recent years in Afognak Lake. Temperatures in the lake were near the 24-year average (1989–2012) for limnology sampling (Appendix A5) and

within the last three years for temperature logger data (Table 9; Appendices A13 and A14). The lake was stratified from May through July (Figure 10). DO and light penetration values were slightly above the 24-year average (Appendices A6 and A7). Euphotic zone depth (EZD) values indicated that, on average, the first 9.8 m of the water column at the sampling stations were photosynthetically active. With an average depth of 8.6 m, this suggests that the majority of Afognak Lake was capable of primary production. Historic mean EZD values were slightly less than those in 2012, with 9.4 m of the water column being photosynthetically active (1987–2011; Appendix A7).

Seasonal measurements of mean nutrient and algal pigment concentrations generally showed little variation over the sampling season, with the exception of nitrogen components. From a historical perspective, pH and alkalinity were slightly above average (Appendix A8), phosphorus components were below average (Appendix A9), nitrogen components were average, except TKN, which was roughly twice the historical average and the highest value ever observed (likely due to near record snow pack runoff; Heather Finkle, ADF&G, personal communication), and algal components were above average. The abundance of nitrogen and decreased phosphorus concentration, coupled with increased chl-*a* (primary production), suggests adequate rates of photosynthesis, thus increased uptake of nitrogen and phosphorus.

Typically, phytoplankton communities are dominated by either diatoms or flagellates (Officer and Ryther 1980). Diatoms are the preferred phytoplankton prey for zooplankton in northern lakes and tend to dominate in oligotrophic systems with sufficient silicon concentration (Officer and Ryther 1980). Low phosphorus levels favor diatom pre-dominance because other species can not compete when levels are low (Heather Finkle, ADF&G, personal communication). Several of the larger lakes in Kodiak, such as Spiridon Lake, are pre-dominated by diatoms (Thomsen 2011). Dominant species of phytoplankton in Afognak have varied over the three years samples have been collected but the species composition typically indicates mesotrophy, and ample nutrient availability for primary production (Heather Finkle, ADF&G, personal communication).

Mean phytoplankton biomass in Afognak Lake has increased in the three years of data collection; peaking in 2012, the biomass was nearly double that of 2011, and nearly 10 times that of 2010 (Appendix A15). Likewise, mean nitrogen (TKN) concentration has increased immensely in the last three years, ranging from 19 in 2010, to 209 in 2011, and to 299 in 2012. The low TKN concentration in 2010 indicates nitrogen was limited, rather than phosphorus, until concentrations increased in 2011. Current values indicate ample nutrient availability, which is supported by the low density of chrysophytes, which thrive at low nutrient levels (Wehr and Sheath 2003).

The seasonal mean zooplankton density and biomass estimates were low in Afognak Lake over the sampling season but above the 5-year average. Data from the two predominate zooplankton taxa, the cladoceran *Bosmina* and the copepod *Epischura*, suggest that juvenile sockeye salmon may affect these key taxa. *Bosmina* had the greatest density in 2012, comprising 54.6% of total average zooplankton density. *Bosmina* were small, and their mean length of 0.30 mm was average for post-fertilization years (2001–2012) but less than pre-fertilization years (1987–1989; 0.32 mm) and below the juvenile sockeye salmon minimum elective feeding threshold of 0.40 mm (Kyle 1992). *Epischura* had the greatest biomass, comprising 53.2% of total average biomass and their mean length of 0.82 mm was well above the juvenile sockeye salmon feeding threshold.

Preliminary results from juvenile sockeye salmon lake sampling indicate a food preference for *Bosmina*, corresponding with findings by Koenings and Burkett (1987) and Kyle (1996), that juvenile sockeye salmon favor cladocerans rather than copepods as a food source. The density of *Bosmina* also suggests that *Bosmina* are outcompeting copepods, indicating that the phytoplankton produced is of small size and *Bosmina* have ample food. Increases in *Epischura* biomass and abundance coincided with the conclusion of the sockeye salmon smolt outmigration from Afognak Lake, which would have resulted in fewer juvenile sockeye salmon remaining in the lake to feed upon zooplankton.

## **ADULT ASSESSMENT**

Adult sockeye salmon escapement has consistently met the lower escapement goal in the last eight years (Table 6; Appendix A12; BEG 20,000–50,000; Nelson et al. 2005). In fact, the sockeye salmon escapement has met or been near the upper end of the BEG in the last three years.

The five-year (2007–2011) average age composition of sockeye salmon is 52.1% age-1.3, 34.0% age-1.2, and 3.5% age-2.2 (Appendix A4). The ten-year (2002–2011) average age composition of sockeye salmon is 41.7% age-1.3, 31.1% age-1.2, and 7.5% age-2.2. The twenty-year (1992–2011) average age composition of sockeye salmon is composed of 37.8% age-1.3, 24.6% age-1.2, and 8.9% age-2.2.

Weir counts through 15 August do not allow complete monitoring of adult coho salmon escapement at Afognak Lake but escapement has averaged approximately 6,000 fish since the 80s (SEG 3,500–8,000; Nelson et al. 2005). Assuming consistent run timing, returns have been sizeable in the last three years but were depressed from 2003 through 2009. Considering concerns about possible competition and predation on juvenile sockeye salmon in Afognak Lake by juvenile coho salmon, it would be prudent to extend weir operations through 31 August, to more closely monitor coho escapement.

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Product names used in this publication are included for completeness but do not constitute product endorsement.

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## **TABLES AND FIGURES**

Table 1.—Estimated abundance of sockeye salmon smolt emigrating from Afognak Lake, 2012.

Stratum (h)	Starting date	Ending date	Catch ( $u_h$ )	Released ( $M_h$ )	Recaptured ( $m_h$ )	Carlson Trap efficiency (%)	Estimate ( $U_h$ )	Variance ( $U_h$ )	95% Confidence Interval	
									lower	upper
1	5/8	6/1	5,197	350	69	20.0	26,037	7.75.E+06	20,583	31,492
2	6/2	6/7	4,010	314	43	14.0	28,744	1.60.E+07	20,911	36,578
3	6/8	6/15	7,933	347	78	22.7	34,988	1.20.E+07	28,213	41,764
4	6/16	6/23	4,672	438	55	12.8	36,632	2.08.E+07	27,696	45,568
5	6/24	6/28	280	463	88	19.2	1,460	2.52.E+04	1,149	1,771
Total			22,092	1,913	333	17.7	127,862	5.65.E+07	98,551	157,173
SE=7,515										

Table 2.—Sockeye salmon smolt catch, number of AWL samples collected, mark-recapture releases, recoveries, and trap efficiency estimates from Afognak River by stratum, 2012.

Date	Daily Catch	AWL Samples	Marked Releases <sup>a</sup>	Marked Recoveries	Carlson Trap Efficiency
Stratum 1					
8-May	3	0	0	0	20.0%
9-May	1	0	0	0	20.0%
10-May	3	0	0	0	20.0%
11-May	0	0	0	0	20.0%
12-May	3	0	0	0	20.0%
13-May	1	0	0	0	20.0%
14-May	3	0	0	0	20.0%
15-May	9	0	0	0	20.0%
16-May	16	4	0	0	20.0%
17-May	32	5	0	0	20.0%
18-May	39	5	0	0	20.0%
19-May	18	5	0	0	20.0%
20-May	20	5	0	0	20.0%
21-May	43	5	0	0	20.0%
22-May	142	5	0	0	20.0%
23-May	662	10	0	0	20.0%
24-May	213	5	0	0	20.0%
25-May	596	15	0	0	20.0%
26-May	449	10	0	0	20.0%
27-May	147	10	0	0	20.0%
28-May	1,018	25	538	57	20.0%
29-May	782	15	0	7	20.0%
30-May	297	5	0	2	20.0%
31-May	229	5	0	1	20.0%
1-Jun	471	10	0	2	20.0%
Total Stratum 1	5,197	144	538	69	20.0%
Stratum 2					
2-Jun	157	4	393	27	14.0%
3-Jun	388	5	0	6	14.0%
4-Jun	1,114	20	0	6	14.0%
5-Jun	1,047	25	0	1	14.0%
6-Jun	365	10	0	2	14.0%
7-Jun	939	20	0	1	14.0%
Total Stratum 2	4,010	84	393	43	14.0%

-continued-

Table 2.–Page 2 of 2.

Date	Daily Catch	AWL Samples	Marked Releases <sup>a</sup>	Marked Recoveries	Carlson Trap Efficiency
Stratum 3					
8-Jun	1,479	30	367	60	22.7%
9-Jun	458	10	0	15	22.7%
10-Jun	1,272	25	0	2	22.7%
11-Jun	510	20	0	0	22.7%
12-Jun	1,017	20	0	0	22.7%
13-Jun	1,360	25	0	1	22.7%
14-Jun	1,078	20	0	0	22.7%
15-Jun	759	15	0	0	22.7%
Total Stratum 3	7,933	165	367	78	22.7%
Stratum 4					
16-Jun	1,537	30	444	29	12.8%
17-Jun	834	15	0	19	12.8%
18-Jun	870	20	0	6	12.8%
19-Jun	494	10	0	1	12.8%
20-Jun	292	5	0	0	12.8%
21-Jun	481	10	0	0	12.8%
22-Jun	132	5	0	0	12.8%
23-Jun	32	5	0	0	12.8%
Total Stratum 4	4,672	100	444	55	12.8%
Stratum 5					
24-Jun	96	5	463	47	19.2%
25-Jun	89	5	0	41	19.2%
26-Jun	33	5	0	0	19.2%
27-Jun	41	0	0	0	19.2%
28-Jun	21	0	0	0	19.2%
Total Stratum 5	280	15	463	88	19.2%
Total Strata 1-5	22,092	508	2,205	333	17.7%

<sup>a</sup> The number of marked releases for each strata were adjusted using delayed mortality tests. For example, in stratum 3, five of the 75 (5.3%) marked fish held for delayed mortality died, so the release (367) was lowered by 5.3% to 347.

Table 3.–Theoretical production of Afognak Lake sockeye salmon eggs, emergent fry, and smolt by age from brood years 2009 and 2010 and predicted smolt outmigration for 2012.

Production		Brood Year		Estimate 2012
Parameter	Assumption	2009	2010	FW-Age-1 and -2 smolt
Escapement		31,358	52,255	
Females spawners	51% (2009) 61% (2010) <sup>a</sup>	15,993	31,876	
Deposited Eggs	2,591 (2009) 2,539 (2010) <sup>b</sup>	40,445,235	80,933,164	
Emergent Fry	7% egg-to-fry survival <sup>c</sup>	2,831,166	5,665,321	
Smolt	21% fry-to-smolt survival <sup>d</sup>	594,545	1,189,718	
2012 Smolt Emigration	74% FW-age-1, 26% FW-age-2 <sup>e</sup>	155,592	878,368	1,033,961

<sup>a</sup> Female sex composition derived from 2009 and 2010 sex data obtained from adult age, length, and sex sampling.

<sup>b</sup> Actual fecundity of Afognak Lake sockeye salmon as reported from Pillar Creek Hatchery (2009 and 2010).

<sup>c</sup> Egg to fry survival assumption from Drucker (1970), Bradford (1995), and Koenings and Kyle (1997).

<sup>d</sup> Fry to smolt survival assumptions from Koenings and Kyle (1997).

<sup>e</sup> Age composition assumptions derived from the average 2012 smolt age class estimate.

Table 4.–Estimated outmigration abundance of Afognak Lake sockeye salmon smolt by time period (stratum) and age class, 2012.

Stratum	Date		Freshwater Age			Total
			1	2	3	
1	(5/8-6/1)	Number	10,412	15,626	0	26,038
		Percent	40.0%	60.0%	0.0%	
2	(6/2-6/7)	Number	22,448	6,296	0	28,744
		Percent	78.1%	21.9%	0.0%	
3	(6/8-6/15)	Number	32,861	2,127	0	34,988
		Percent	93.9%	6.1%	0.0%	
4	(6/16-6/23)	Number	32,389	4,242	0	36,632
		Percent	88.4%	11.6%	0.0%	
5	(6/24-6/28)	Number	1,430	30	0	1,460
		Percent	98.0%	2.0%	0.0%	
Total		Number	99,541	28,321	0	127,862
		Percent	77.9%	22.1%	0.0%	

Table 5.–Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2012.

Stratum	Dates	Sample Size	Weight (g)		Length (mm)		Condition	
			Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Freshwater-Age-1								
1	(5/8-6/1)	49	2.6	0.06	69.1	0.50	0.77	0.006
2	(6/2-6/7)	66	2.7	0.04	70.2	0.35	0.79	0.007
3	(6/8-6/15)	155	3.1	0.03	72.5	0.22	0.81	0.004
4	(6/16-6/23)	89	3.5	0.03	75.1	0.23	0.83	0.006
5	(6/24-6/28)	19	3.8	0.10	76.5	0.52	0.84	0.010
Totals		378	3.1	0.03	72.5	0.18	0.81	0.003
Freshwater-Age-2								
1	(5/8-6/1)	94	3.9	0.05	79.2	0.30	0.77	0.005
2	(6/2-6/7)	18	3.7	0.13	78.5	0.75	0.76	0.012
3	(6/8-6/15)	10	3.8	0.17	78.9	0.84	0.78	0.022
4	(6/16-6/23)	11	4.2	0.27	80.1	1.60	0.80	0.014
5	(6/24-6/28)	1	4.2	0.00	79.0	0.00	0.85	0.000
Totals		134	3.9	0.05	79.1	0.27	0.78	0.005

Table 6.—Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978–2012.

Year	Escapement	Harvest <sup>c</sup>			Total Run
		Commercial <sup>a</sup>	Subsistence <sup>b</sup>	Total	
1978	52,701	3,414	1,632	5,046	57,747
1979	82,703	2,146	2,069	4,215	86,918
1980	93,861	28	3,352	3,380	97,241
1981	57,267	16,990	3,648	20,638	77,905
1982	123,055	21,622	3,883	25,505	148,560
1983	40,049	4,349	3,425	7,774	47,823
1984	94,463	6,130	3,121	9,251	103,714
1985	53,563	1,980	6,804	8,784	62,347
1986	48,328	2,585	3,450	6,035	54,363
1987	25,994	1,323	2,767	4,090	30,084
1988	39,012	14	2,350	2,364	41,376
1989	88,825	0	3,859	3,859	92,684
1990	90,666	22,149	4,469	26,618	117,284
1991	88,557	47,237	5,899	53,136	141,693
1992	77,260	2,196	4,638	6,834	84,094
1993	71,460	1,848	4,580	6,428	77,888
1994	80,570	17,362	3,329	20,691	101,261
1995	100,131	67,665	4,390	72,055	172,186
1996	101,718	106,141	11,023	117,164	218,882
1997	132,050	10,409	12,412	22,821	154,871
1998	66,869	26,060	4,690	30,750	97,619
1999	95,361	34,420	5,628	40,048	135,409
2000	54,064	14,124	7,572	21,696	75,760
2001	24,271	0	4,720	4,720	28,991
2002	19,520	0	1,279	1,279	20,799
2003	27,766	0	604	604	28,370
2004	15,181	0	567	567	15,748
2005	21,577	356	696	1,052	22,629
2006	22,933	6	451	457	23,390
2007	21,070	0	490	490	21,560
2008	26,874	1,098	594	1,692	28,566
2009	31,358	363	971	1,334	32,692
2010	52,255	9,755	2,146	11,901	64,156
2011	49,193	13,952	1,770	15,722	64,915
2012	41,553	3,398	1,706	5,104	46,657

<sup>a</sup> Statistical fishing section 252-34 (Southeast Afognak Section).

<sup>b</sup> Data as of 04/15/2013 from ADF&G subsistence catch database 1978–2012.

<sup>c</sup> Sport harvest data does not have enough respondents to provide reliable estimates and was determined to be negligible.

Table 7.—Afognak Lake adult sockeye salmon escapement by statistical week and age class, 2012.

Stat Week	Dates	Sample		Age							Total Fish
		Size		1.1	1.2	1.3	1.4	2.1	2.2	2.3	
21	May 17 - May 23	0	Percent	0.0	1.9	81.1	0.0	0.0	3.8	13.2	10
			Numbers	0	0	8	0	0	0	1	
22	May 24 - May 30	0	Percent	0.0	1.9	81.1	0.0	0.0	3.8	13.2	51
			Numbers	0	1	41	0	0	2	7	
23	May 31 - Jun 06	53	Percent	0.2	4.0	78.4	0.0	0.0	4.0	13.3	6,185
			Numbers	26	360	4,710	0	0	262	827	
24	Jun 07 - June 13	253	Percent	2.3	16.5	62.0	0.0	0.1	6.3	12.8	13,483
			Numbers	294	2,166	8,440	0	11	837	1,734	
25	Jun 14 - Jun 20	175	Percent	5.6	19.8	54.0	0.0	0.4	11.6	8.6	6,818
			Numbers	410	1,370	3,624	0	34	833	547	
26	Jun 21 - Jun 27	52	Percent	1.4	18.1	45.7	0.0	0.5	25.1	9.2	3,910
			Numbers	56	706	1,792	0	16	980	360	
27	Jun 28 - Jul 04	38	Percent	1.0	19.7	40.5	0.0	4.2	24.6	9.9	2,581
			Numbers	3	473	1,051	0	100	689	264	
28	Jul 05 - Jul 11	73	Percent	6.2	26.7	42.6	0.2	2.9	13.5	7.8	1,530
			Numbers	82	379	668	7	38	229	126	
29	Jul 12 - Jul 18	64	Percent	1.0	15.5	46.8	1.3	1.8	23.7	9.9	3,115
			Numbers	97	624	1,411	30	63	601	290	
30	Jul - 19 - Jul 25	0	Percent	0.0	9.8	51.0	0.7	2.4	29.5	6.7	1,309
			Numbers	0	134	662	11	30	380	93	
31	Jul 26 - Aug 01	33	Percent	0.0	12.8	46.4	0.1	2.4	34.6	3.7	1,350
			Numbers	0	178	619	0	33	472	48	
32	Aug 02 - Aug 08	19	Percent	0.0	38.2	15.2	0.0	0.3	41.2	5.0	387
			Numbers	0	156	49	0	1	161	20	

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Table 7.—Page 2 of 2.

Stat Week	Dates	Sample Size		Age							Total Fish
				1.1	1.2	1.3	1.4	2.1	2.2	2.3	
33	Aug - 09 - Aug 15	7	Percent	0.0	3.0	53.8	0.0	0.0	42.8	0.4	633
			Numbers	0	5	356	0	0	271	1	
34	Aug 16 - Aug 22	0	Percent	0.0	57.1	0.0	0.0	0.0	42.9	0.0	81
			Numbers	0	46	0	0	0	35	0	
35	Aug 23 - Aug 29	0	Percent	0.0	57.1	0.0	0.0	0.0	42.9	0.0	110
			Numbers	0	63	0	0	0	47	0	
Totals		767	Percent	2.3	15.7	56.7	0.1	0.8	14.0	10.4	100.0
			Numbers	968	6,531	23,565	48	325	5,800	4,315	41,553

Table 8.—Mean length of Afognak Lake adult sockeye salmon escapement by sex and age class, 2012.

	Age							Total
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	
Males								
Mean Length (mm)	323.9	471.4	551.8	0.0	344.9	494.0	542.1	505.5
Standard Error	4.05	5.40	2.24	0.00	10.83	4.21	5.83	4.16
Range	295-380	380-585	459-625		305-395	441-572	452-590	295-625
Sample Size	22	59	145	0	7	46	26	305
Females								
Mean Length (mm)	0.0	469.9	531.5	560.0	0.0	477.2	521.4	512.9
Standard Error	0.00	3.05	1.56	0.00	0.00	3.51	3.36	3.39
Range		422-547	352-585	560-560		415-547	450-564	352-585
Sample Size	0	78	269	1	0	60	52	460
All								
Mean Length (mm)	323.9	470.6	538.6	560.0	344.9	484.5	528.3	509.9
Standard Error	4.05	2.89	1.37	0.00	10.83	2.81	3.15	1.96
Range	295-380	380-585	352-625	560-560	305-395	415-572	450-590	295-625
Sample Size	22	137	414	1	7	106	78	765

Table 9.–Data logger temperatures (°C) at station 2, 1 meter, for Afognak Lake, 2012.

Month	Mean	Max	Min	Daily Variation	
				Mean	Max
May	7.3	9.5	5.7	0.7	1.9
June	12.3	16.7	8.1	1.1	2.6
July	14.4	17.3	12.4	0.8	2.9
August	14.8	16.3	14.3	0.5	1.5
September	12.5	15.0	9.8	0.3	0.7
October	9.4	9.9	9.2	0.2	0.3

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
Spring	9.8	16.7	5.7	0.9	2.6
Summer	14.6	17.3	12.4	0.7	2.9
Fall	11.0	15.0	9.2	0.3	0.7

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
(May-Oct)	12.6	17.3	5.7	0.7	2.9

*Note:* Mean variation is the monthly mean difference between daily maximum and minimum temperatures. Max variation is the monthly maximum difference between daily maximum and minimum temperatures. Spring consists of May-June, Summer consists of July-August, and Fall consists of September-October.

Table 10.—General water chemistry and algal pigment concentrations at 1 m water depth, station 1, Afognak Lake, 2012.

	pH	Alkalinity	Chlorophyll <i>a</i>	Pheophytin <i>a</i>
Date	(units)	(mg L <sup>-1</sup> )	(µg L <sup>-1</sup> )	(µg L <sup>-1</sup> )
24-May	7.27	11.0	1.12	0.11
16-Jun	7.46	10.5	1.12	0.11
10-Jul	7.73	10.0	2.24	0.22
17-Aug	7.52	12.0	1.92	0.10
24-Sep	7.29	12.0	2.31	0.05
Average	7.45	11.1	1.74	0.12
SD	0.19	0.9	0.59	0.06

Table 11.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2012.

	Total	Filterable		Reactive		Total Kjeldahl	Nitrate +	Total	
	filterable-P	reactive-P	Total-P	Silicon	Ammonia	Nitrogen	Nitrite	Nitrogen	TN:TP
Date	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	( $\mu\text{g L}^{-1}$ )	ratio
24-May	2.0	0.8	3.8	3,065.3	6.6	395.0	86.9	481.9	280.8
16-Jun	1.5	1.1	3.8	2,961.9	3.1	288.1	54.3	342.4	199.5
10-Jul	1.6	0.8	4.0	2,886.1	1.5	302.1	11.1	313.2	173.4
17-Aug	1.9	0.4	3.7	2,567.8	10.6	235.2	1.9	237.1	141.9
24-Sep	1.6	0.8	3.5	2,546.8	7.3	273.3	13.5	286.8	181.4
Average	1.7	0.8	3.8	2,805.6	5.8	298.7	33.5	332.3	195.4
SD	0.2	0.2	0.2	235.5	3.6	59.3	36.0	92.2	52.1

Table 12.—Seasonal weighted mean zooplankton density, biomass, and size by individual station from Afognak Lake, 2012.

Station	<i>n</i>		<i>Epischura</i>	<i>Diaptomus</i>	<i>Cyclops</i>	Other Copepods	<i>Bosmina</i>	<i>Daphnia</i>	<i>Holopedium</i>	Other Cladocerans	Total Copepods	Total Cladocerans	Total all zooplankton
1	5	density (no. m <sup>2</sup> )	23,928	425	3,854	12,771	56,359	4,310	1,104	5,478	40,977	67,251	108,227
		%	22.1%	0.4%	3.6%	11.8%	52.1%	4.0%	1.0%	5.1%	37.9%	62.1%	100.0%
		biomass (mg m <sup>2</sup> )	82.0	1.0	5.8	— <sup>a</sup>	44.5	6.9	2.8	— <sup>a</sup>	88.7	54.1	142.8
		%	57.4%	0.7%	4.0%	— <sup>a</sup>	31.1%	4.8%	1.9%	— <sup>a</sup>	62.1%	37.9%	100.0%
		size (mm)	0.91	0.81	0.66	— <sup>a</sup>	0.30	0.64	0.53	— <sup>a</sup>			
2	5	density (no. m <sup>2</sup> )	8,386	1,699	1,964	8,333	37,155	743	955	3,928	20,382	42,781	63,163
		%	13.3%	2.7%	3.1%	13.2%	58.8%	1.2%	1.5%	6.2%	32.3%	67.7%	100.0%
		biomass (mg m <sup>2</sup> )	29.4	4.0	2.4	— <sup>a</sup>	27.8	1.0	1.9	— <sup>a</sup>	35.9	30.8	66.7
		%	44.1%	6.0%	3.6%	— <sup>a</sup>	41.7%	1.6%	2.9%	— <sup>a</sup>	53.8%	46.2%	100.0%
		size (mm)	0.97	0.81	0.61	— <sup>a</sup>	0.29	0.57	0.49	— <sup>a</sup>			
All Data		density (no. m <sup>2</sup> )	16,157	1,062	2,909	10,552	46,757	2,527	1,030	4,703	30,679	55,016	85,695
		%	18.9%	1.2%	3.4%	12.3%	54.6%	2.9%	1.2%	5.5%	35.8%	64.2%	100.0%
		biomass (mg m <sup>2</sup> )	55.7	2.5	4.1	— <sup>a</sup>	36.1	4.0	2.3	— <sup>a</sup>	62.3	42.4	104.7
		%	53.2%	2.4%	3.9%	— <sup>a</sup>	34.5%	3.8%	2.2%	— <sup>a</sup>	59.5%	40.5%	100.0%
		size (mm)	0.94	0.81	0.64	— <sup>a</sup>	0.29	0.61	0.51	— <sup>a</sup>			

<sup>a</sup> Other copepods and cladocerans are composed of immature species that are too small to measure to generate a biomass estimate.

Table 13.–Summary of Afognak Lake phytoplankton monthly and mean biomass, by phylum, 2012.

		Phylum							
		Chlorophyta (Green Algae)	Chrysophyta (Golden-brown Algae)	Bacillariophyta (Diatoms)	Cryptophyta (cryptomonads)	Pyrrophyta (Dinoflagellate)	Haptophyta	Cyanobacteria (Blue-green Algae)	Total
Date	Station	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )
24-May	1	1.78	0.00	406.42	34.64	275.30	0.00	0.00	718.14
16-Jun	1	124.94	0.00	737.58	5.73	68.54	0.00	0.21	937.00
10-Jul	1	18.50	0.00	515.11	422.26	701.82	0.00	47.67	1705.36
17-Aug	1	93.81	0.00	1046.31	88.34	0.00	0.00	29.73	1258.18
24-Sep	1	23.12	0.00	936.55	120.89	3.71	0.00	12.53	1096.80
Mean		52.43	0.00	728.39	134.37	209.87	0.00	18.03	1143.10

Table 14.–Summary of Afognak Lake phytoplankton monthly and mean biomass, by phylum, 2011.

		Phylum							
		Chlorophyta (Green Algae)	Chrysophyta (Golden-brown Algae)	Bacillariophyta (Diatoms)	Cryptophyta (cryptomonads)	Pyrrophyta (Dinoflagellate)	Haptophyta	Cyanobacteria (Blue-green Algae)	Total
Date	Station	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )
9-May	1	17.79	743.11	328.32	38.03	26.97	3.82	0.00	1158.04
14-Jun	1	29.27	263.83	165.06	54.20	90.52	7.64	45.27	655.79
12-Jul	1	6.49	113.87	176.12	59.72	82.85	32.38	125.17	596.61
8-Aug	1	25.09	76.24	206.68	44.66	4.58	0.00	68.73	425.99
16-Sep	1	8.23	140.18	267.83	3.44	5.61	0.00	12.22	437.51
Mean		17.37	267.45	228.80	40.01	42.11	8.77	50.28	654.79

Table 15.—Length, weight, and condition of lake rearing juvenile sockeye salmon from Afognak Lake, 2012.

Sample Dates by Month		Sample Location	Sample Size	Weight (g)		Length (mm)		Condition	
				Standard Mean	Standard Error	Standard Mean	Standard Error	Standard Mean	Standard Error
Freshwater-Age-0									
May	Shoal	1	0.3		34.0		0.76		
	Mid-lake	0							
June	Shoal	0							
	Mid-lake	8	0.5	0.20	35.5	4.00	1.02	0.32	
July	Shoal	125	1.0	0.53	44.4	6.61	1.03	0.17	
	Mid-lake	3	0.6	0.10	39.3	2.08	0.98	0.04	
August	Shoal	76	2.0	0.68	55.3	6.26	1.16	0.12	
	Mid-lake	49	1.6	0.54	52.5	5.92	1.05	0.08	
September	Shoal	0							
	Mid-lake	0							
October	Shoal	4	2.2	0.43	60.0	3.56	1.01	0.02	
	Mid-lake	24	2.0	0.61	57.7	5.71	1.02	0.11	
Mean	Shoal	206	1.4	0.55	48.4	5.48	0.99	0.10	
	Mid-lake	84	1.2	0.36	46.3	4.43	1.02	0.14	
	All Samples	290	1.3	0.44	47.3	4.88	1.00	0.12	
Freshwater-Age-1									
May	Shoal	13	1.9	0.47	61.8	4.94	0.82	0.18	
	Mid-lake	0							
June	Shoal	25	2.7	0.73	66.6	5.93	0.89	0.11	
	Mid-lake	0							
July	Shoal	0							
	Mid-lake	2	4.6	0.92	73.5	7.78	1.15	0.13	
August	Shoal	20	5.9	0.55	80.2	1.98	1.14	0.10	
	Mid-lake	5	5.7	0.40	79.2	1.30	1.14	0.04	
September	Shoal	0							
	Mid-lake	0							
October	Shoal	0							
	Mid-lake	2	4.7	0.57	77.5	2.12	1.01	0.04	
Mean	Shoal	58	3.5	0.58	69.5	4.28	0.95	0.13	
	Mid-lake	9	5.0	0.63	76.7	3.73	1.10	0.07	
	All Samples	67	4.3	0.61	73.1	4.01	1.03	0.60	
Freshwater-Age-2									
May	Shoal	6	3.2	0.27	74.3	3.01	0.79	0.07	
	Mid-lake	0							
June	Shoal	4	3.6	0.87	75.3	4.99	0.83	0.07	
	Mid-lake	0							
Mean	Shoal	10	3.4	0.57	74.8	4.00	0.81	0.07	
	Mid-lake								
	All Samples	10	3.4	0.57	74.8	4.00	0.81	0.07	
Totals	Shoal	274							
	Mid-lake	93							
	All Samples	367							

Note: One sample was unreadable. No freshwater-age 2 juveniles were captured after June in 2012.

Table 16.—Calories, stomach fullness and percentage of insects and zooplankton within the stomachs of lake rearing juvenile sockeye salmon from Afognak Lake, 2012.

Sample Dates by Month		Sample Location	Sample Size	Stomach Fullness (%)	Insects (%)	Zooplankton (%)	Sample Size	Cal/g	
								Mean	Standard Error
Freshwater-Age-0									
May	Shoal	0					1	6618	
	Mid-lake	0					0		
June	Shoal	0					0		
	Mid-lake	6	50.7	28.4	71.6		2	5731	319
July	Shoal	91	66.4	73.3	25.6		32	5404	360
	Mid-lake	2	62.5	7.5	92.5		1	5403	
August	Shoal	57	66.1	90.3	9.7		19	5618	272
	Mid-lake	35	72.9	47.4	53.1		12	5635	149
September	Shoal	0					0		
	Mid-lake	0					0		
October	Shoal	3	66.7	30.7	69.3		1	5335	
	Mid-lake	15	49.7	19.8	80.2		8	5677	171
Mean	Shoal	151	66.4	64.8	34.9		53	5744	316
	Mid-lake	58	59.0	25.8	74.4		23	5612	213
	All Samples	209	62.1	42.5	57.4		76	5678	254
Freshwater-Age-1									
May	Shoal	8	33.1	47.9	52.1		4	4982	68
	Mid-lake	0					0		
June	Shoal	17	93.5	94.5	5.5		8	5148	253
	Mid-lake	0					0		
July	Shoal	0					0		
	Mid-lake	1	80.0	5.0	95.0		1	5666	
August	Shoal	13	60.0	92.0	8.0		7	5986	68
	Mid-lake	4	68.8	26.0	74.0		1	5852	
September	Shoal	0					0		
	Mid-lake	0					0		
October	Shoal	0					0		
	Mid-lake	2	37.5	78.0	22.0		0		
Mean	Shoal	38	62.2	78.0	22.0		19	5372	130
	Mid-lake	7	62.1	35.4	64.6		2	5759	
	All Samples	45	62.1	57.2	42.8		21	5527	130
Freshwater-Age-2									
May	Shoal	4	35.0	62.0	38.0		2	4732	53
	Mid-lake	0					0		
June	Shoal	1	25.0	100.0	0.0		3	4861	105
	Mid-lake	0					0		
Mean	Shoal	5	30.0	81.0	19.0		5	4797	79
	Mid-lake	0					0		
	All Samples	5	30.0	81.0	19.0		5	4797	79
Totals	Shoal	194					77		
	Mid-lake	65					25		
	All Samples	259					102		

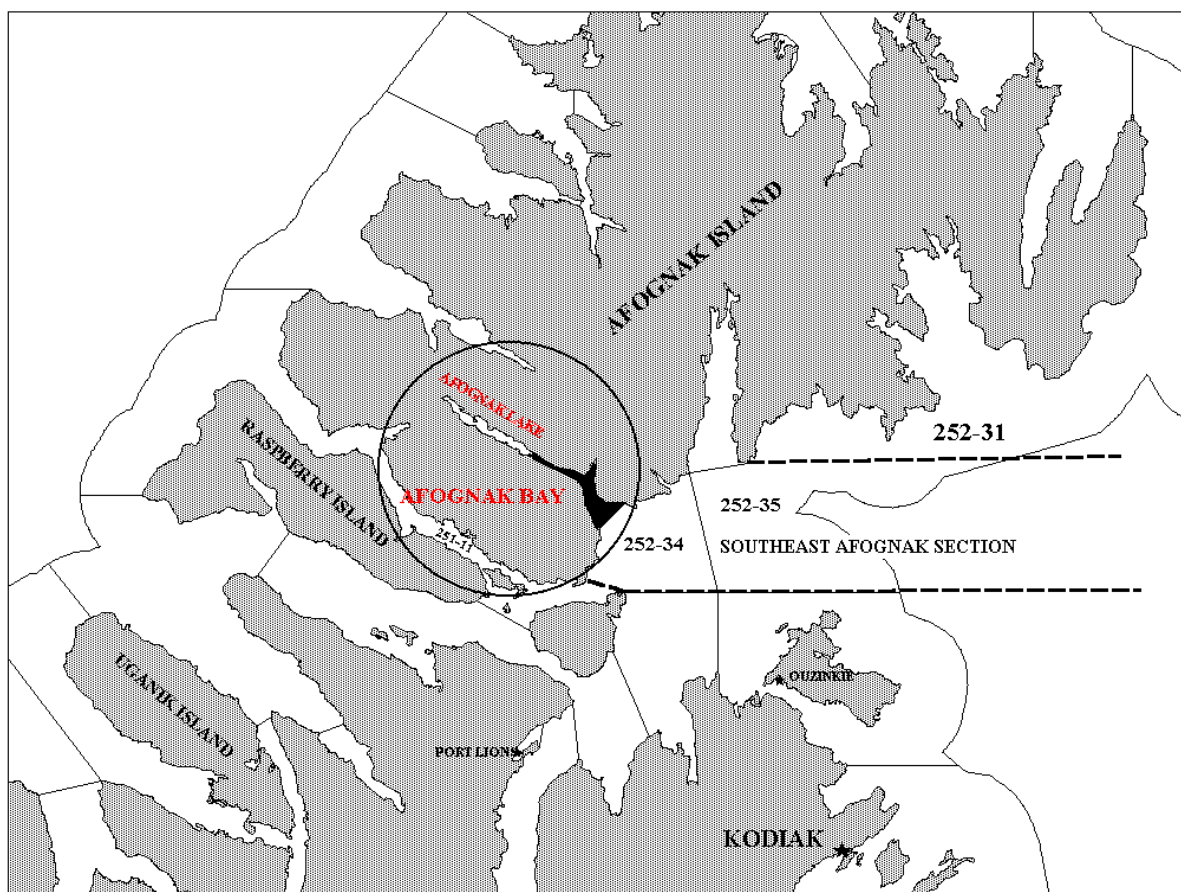


Figure 1.—Map depicting the location of Kodiak City, the villages of Port Lions and Ouzinkie, and their proximity to the Afognak Lake drainage on Afognak Island.

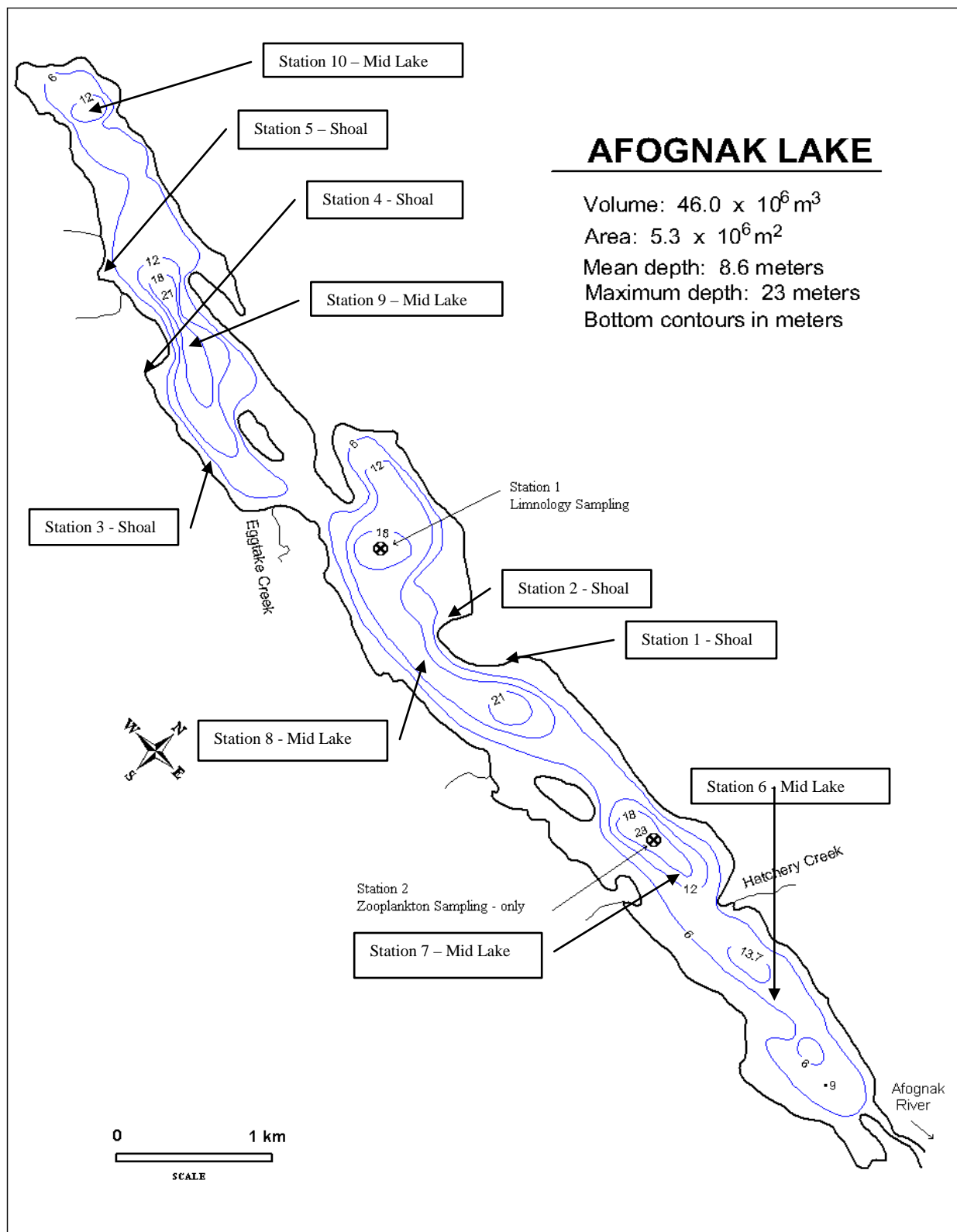


Figure 2.–Bathymetric map showing the limnology, zooplankton, and juvenile lake sampling stations on Afognak Lake.



Figure 3.—Downstream view of the juvenile sockeye salmon trapping system, 2012.



Figure 4.—Downstream view of the adult salmon enumeration weir in Afognak River, 2012.

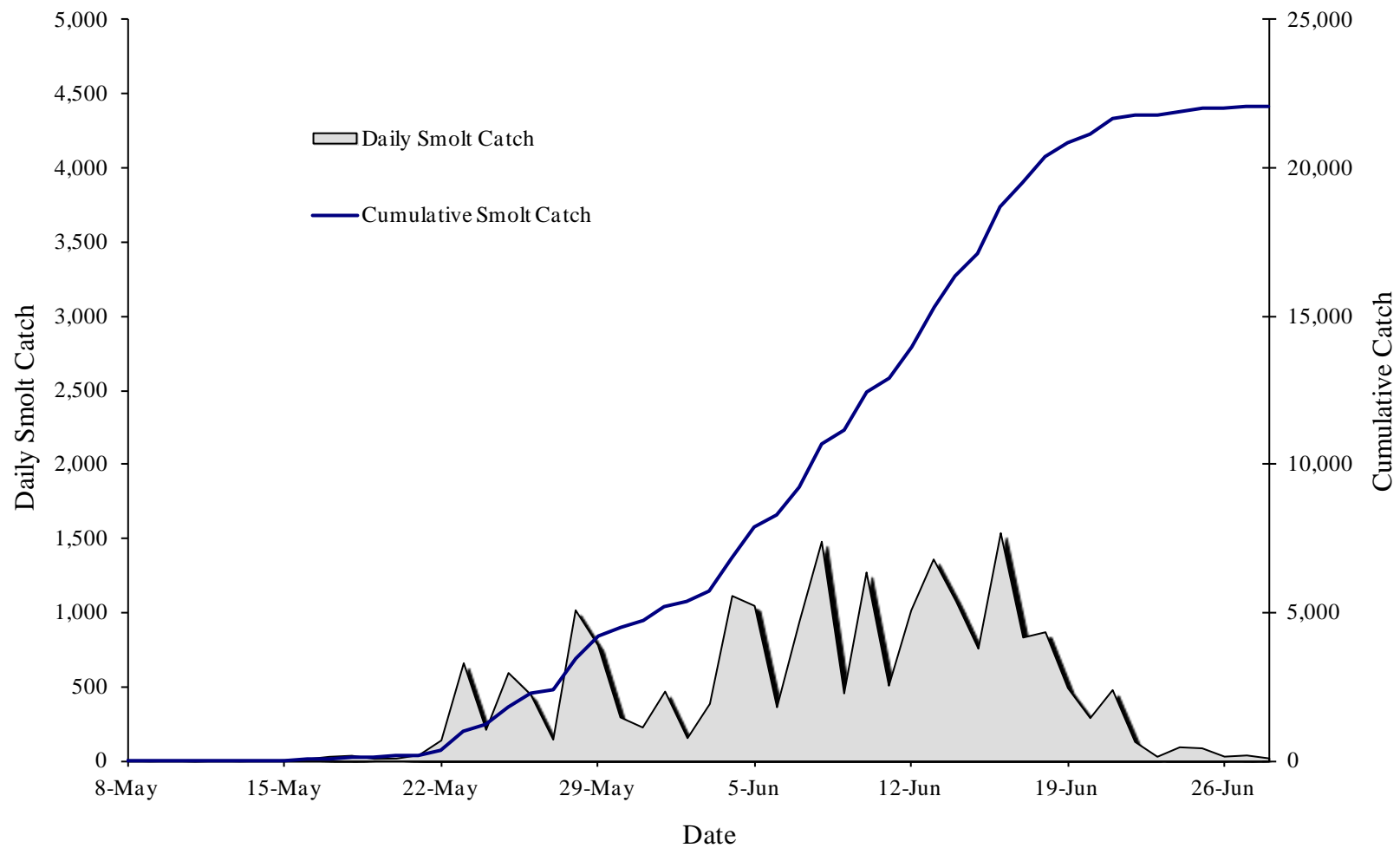


Figure 5.—Daily and cumulative sockeye salmon smolt trap catch from 8 May to 28 June in the Afognak River, 2012.

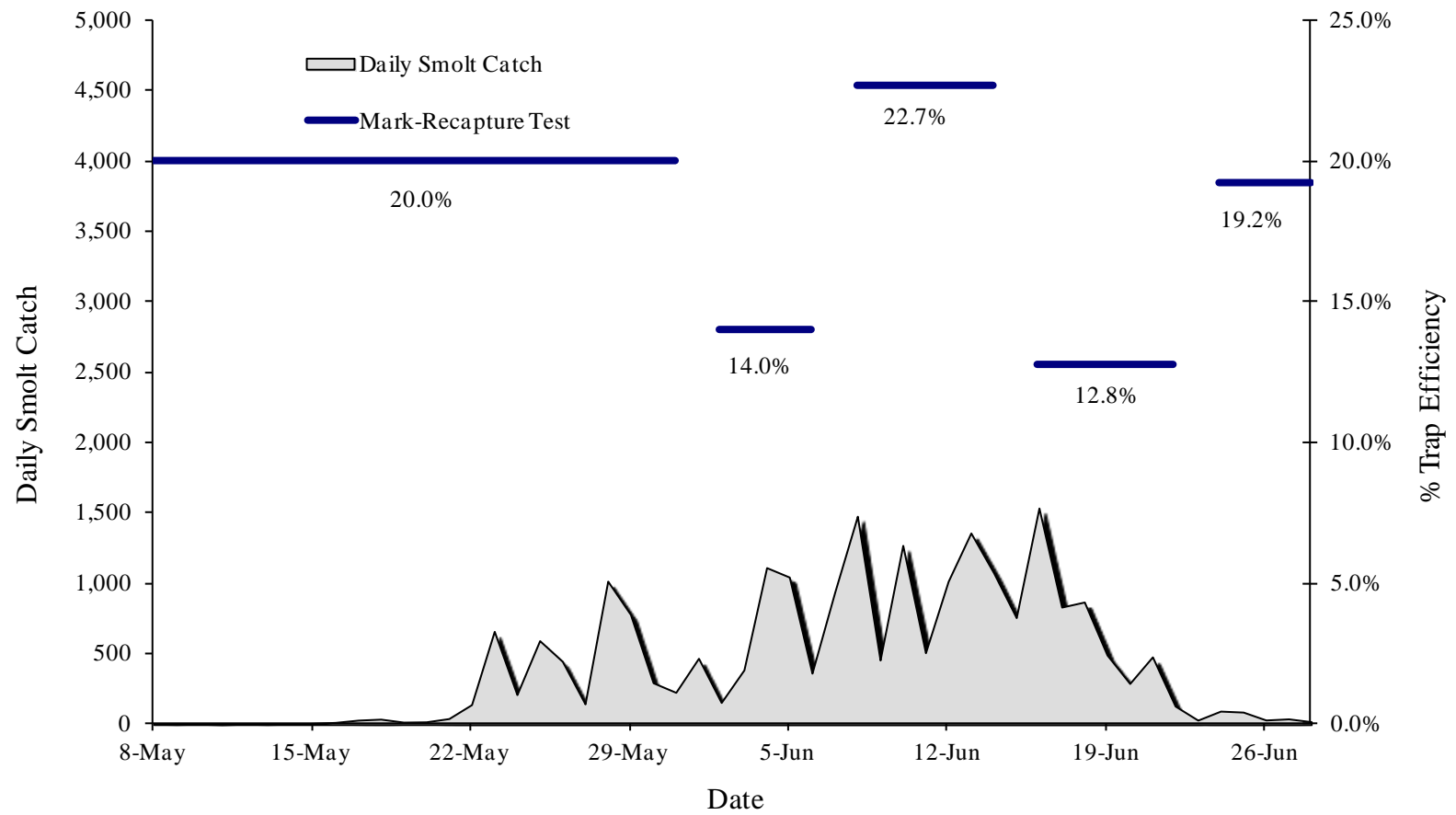
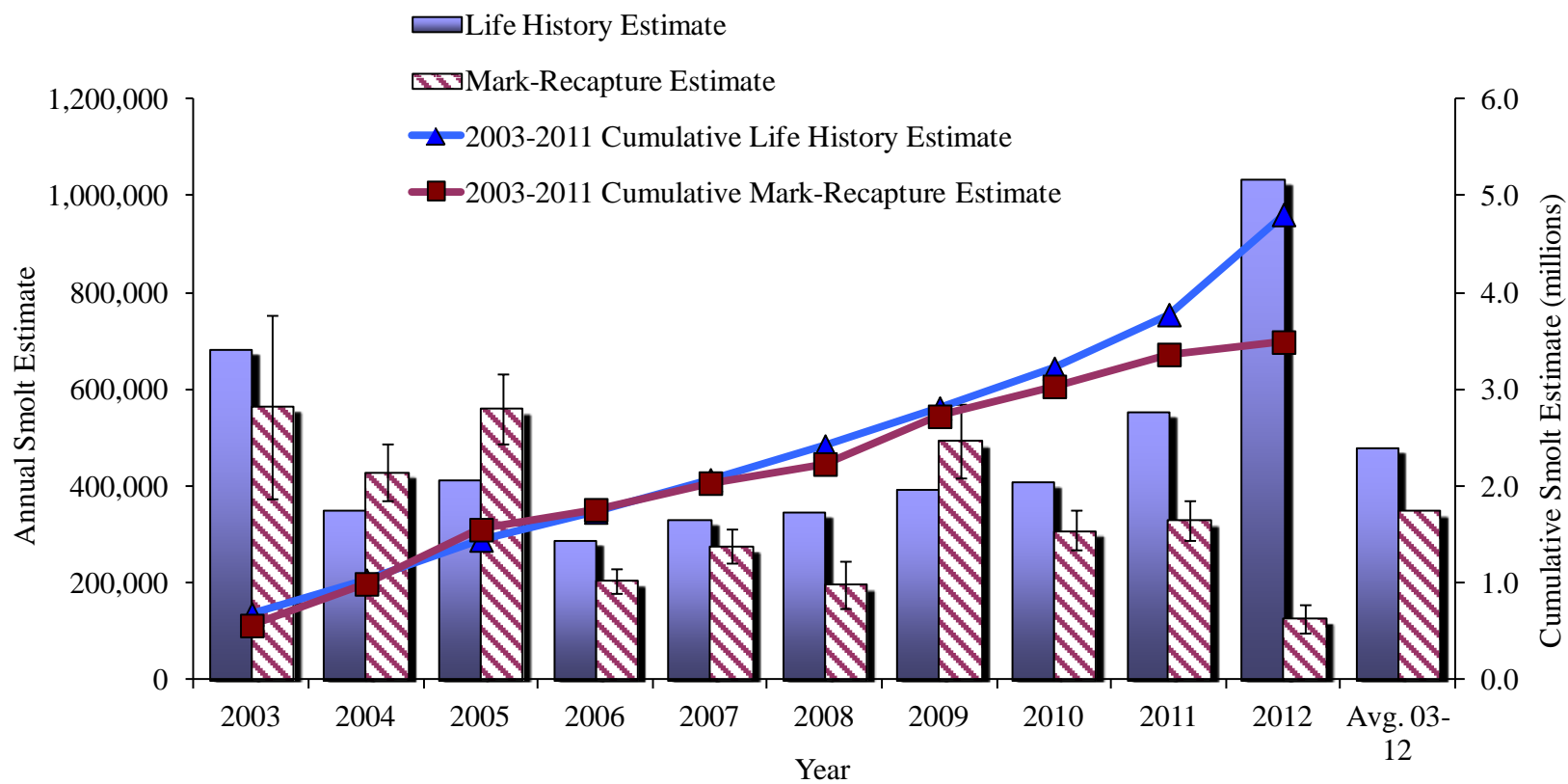


Figure 6.—Daily sockeye salmon smolt trap catch and trap efficiency estimates by strata from 8 May to 28 June in the Afognak River, 2012.



Note: For mark-recapture estimates, the 95% CI is shown as a vertical line superimposed on each bar.

Figure 7.—Comparison of sockeye salmon smolt abundance estimates from life history and mark-recapture models, 2003–2012.

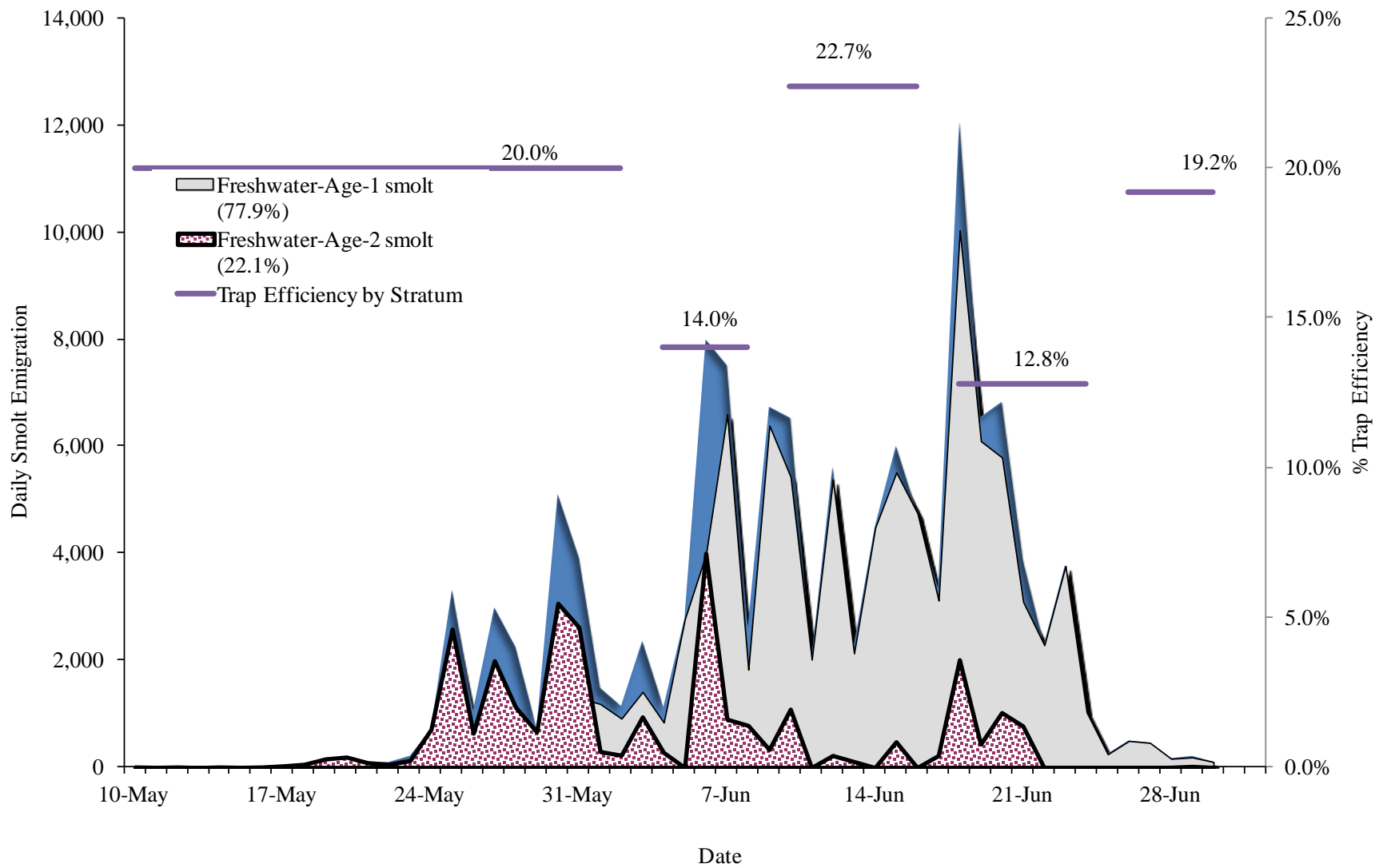


Figure 8.—Afognak Lake sockeye salmon smolt daily outmigration estimates by age class, 2012.

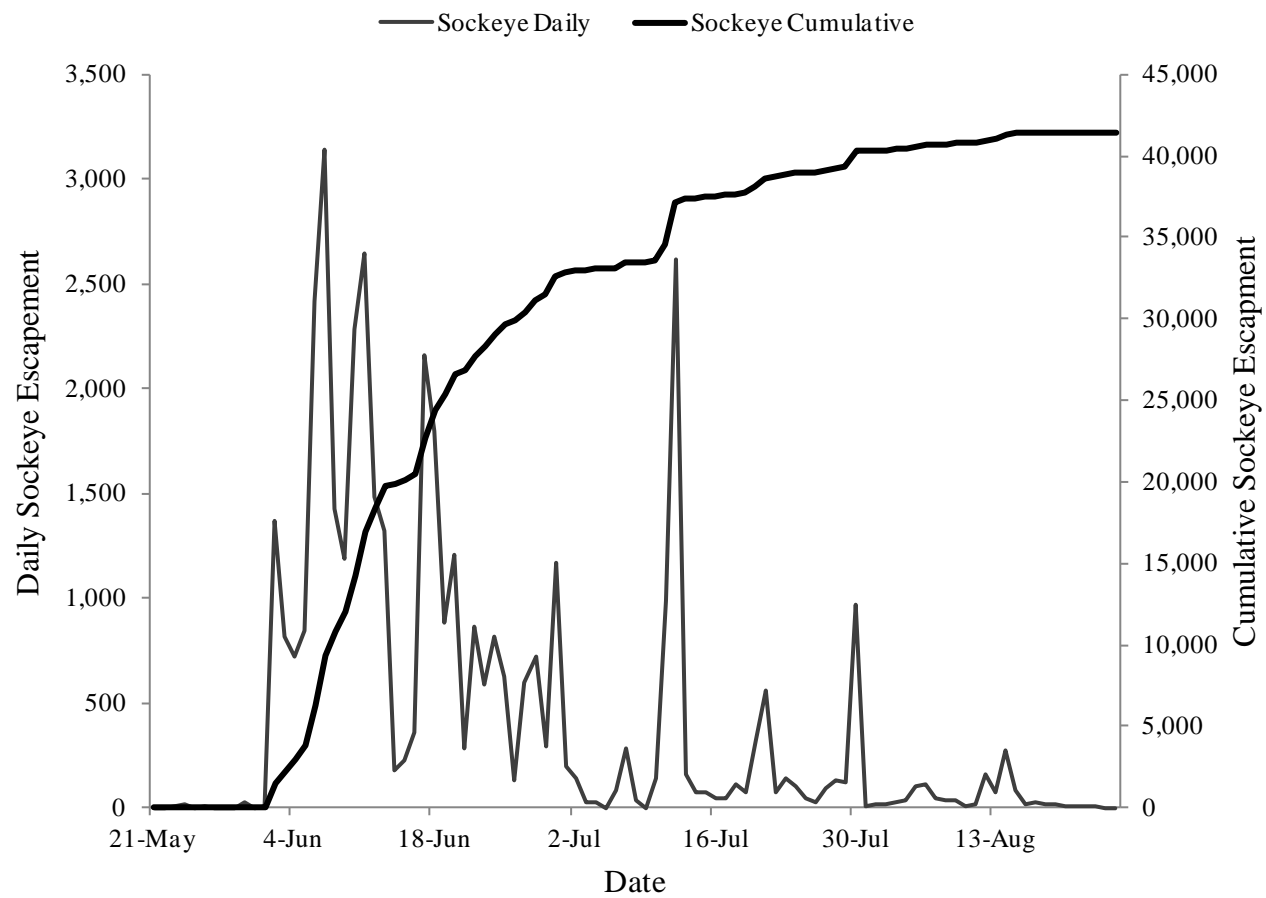


Figure 9.—Afognak Lake adult sockeye salmon daily and cumulative escapement, 2012.

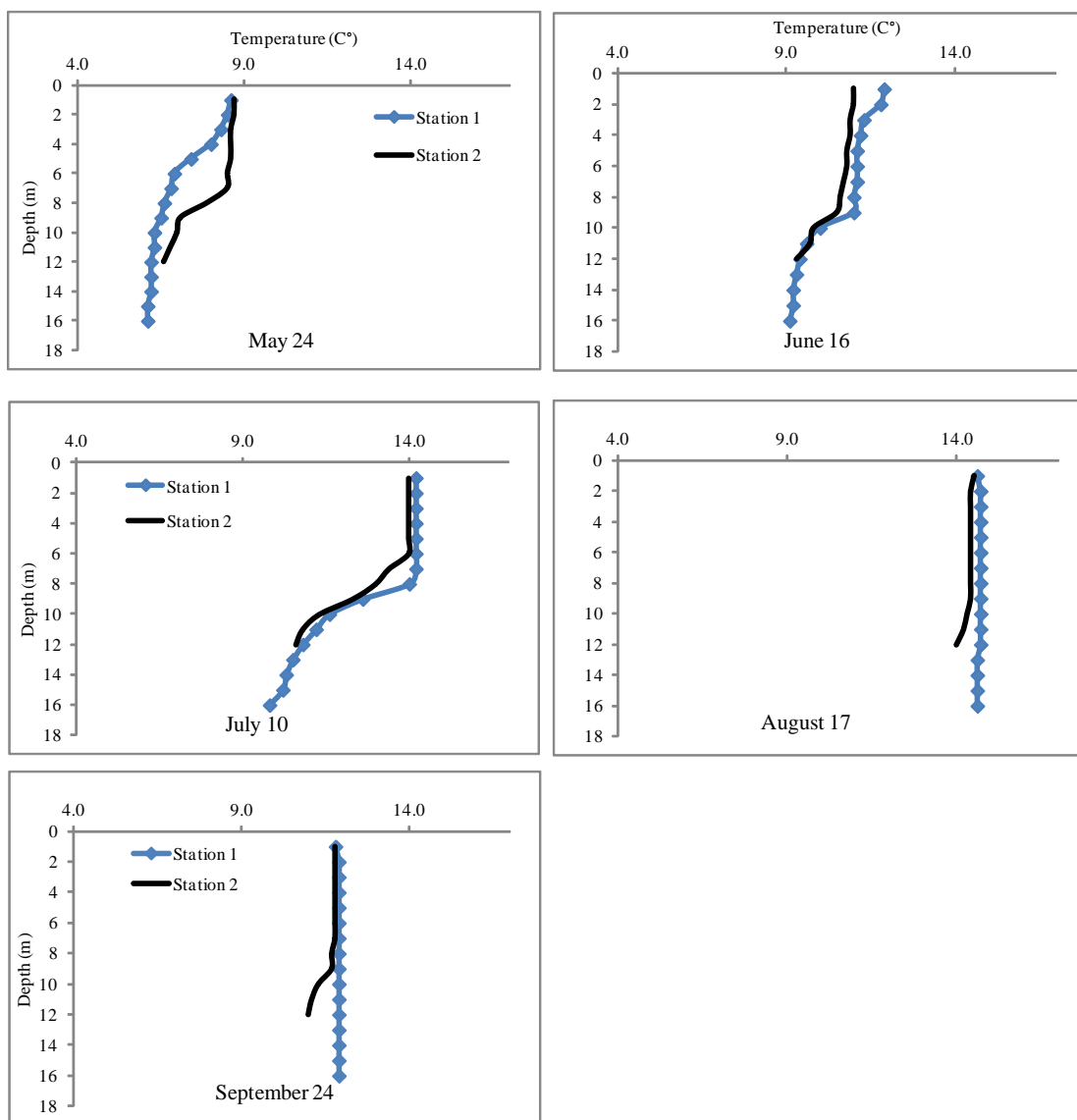


Figure 10.—Temperature profiles by station, by sampling date from Afognak Lake, 2012.

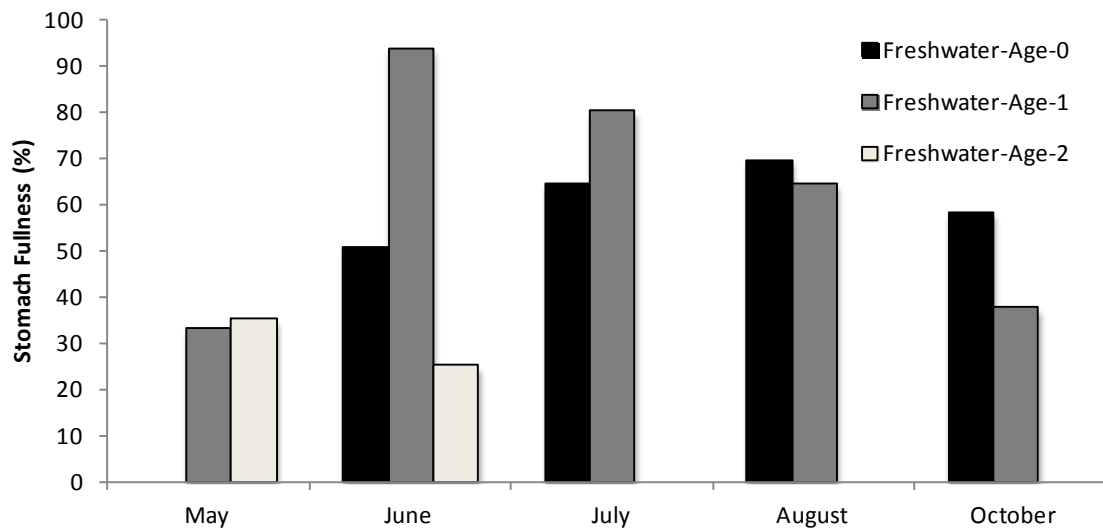


Figure 11.—Stomach fullness of lake rearing juvenile sockeye salmon by age and month from Afognak Lake, 2012.

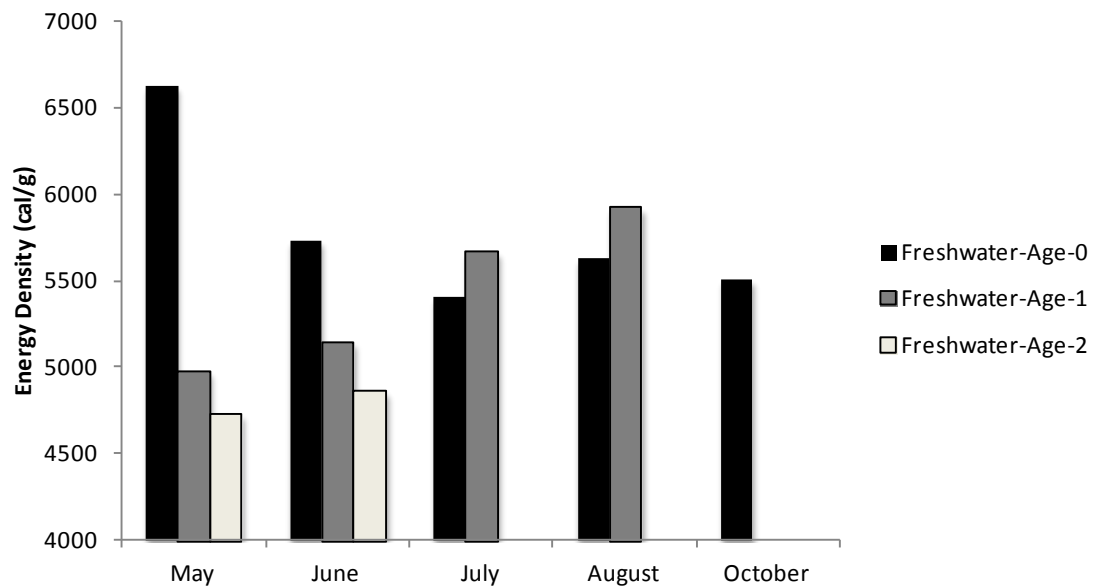


Figure 12.—Calorie content of lake rearing juvenile sockeye salmon by age and month from Afognak Lake, 2012.

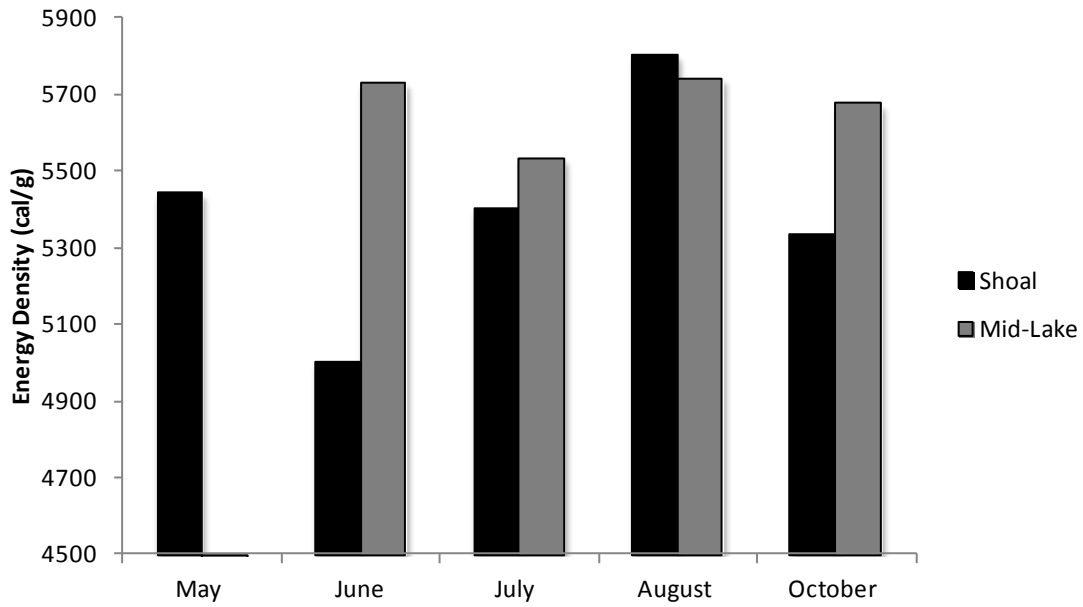


Figure 13.—Calorie content of lake rearing juvenile sockeye salmon by location and month from Afognak Lake, 2012.

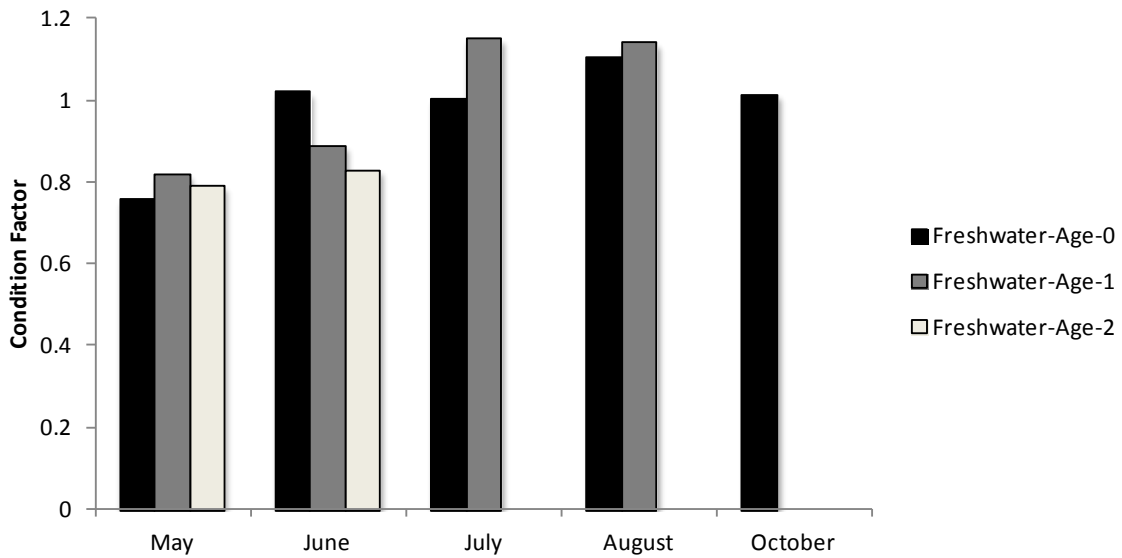


Figure 14.—Condition of lake rearing juvenile sockeye salmon by age and month from Afognak Lake, 2012.

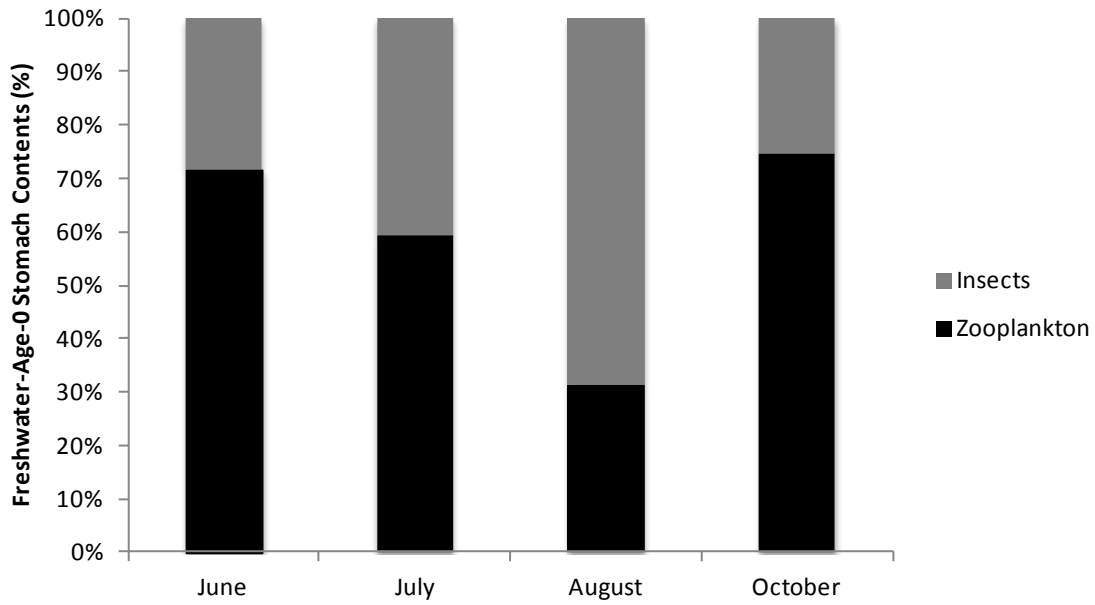


Figure 15.—Percentage of insects and zooplankton within the stomachs of lake rearing freshwater-age-0 juvenile sockeye salmon from Afognak Lake, 2012.

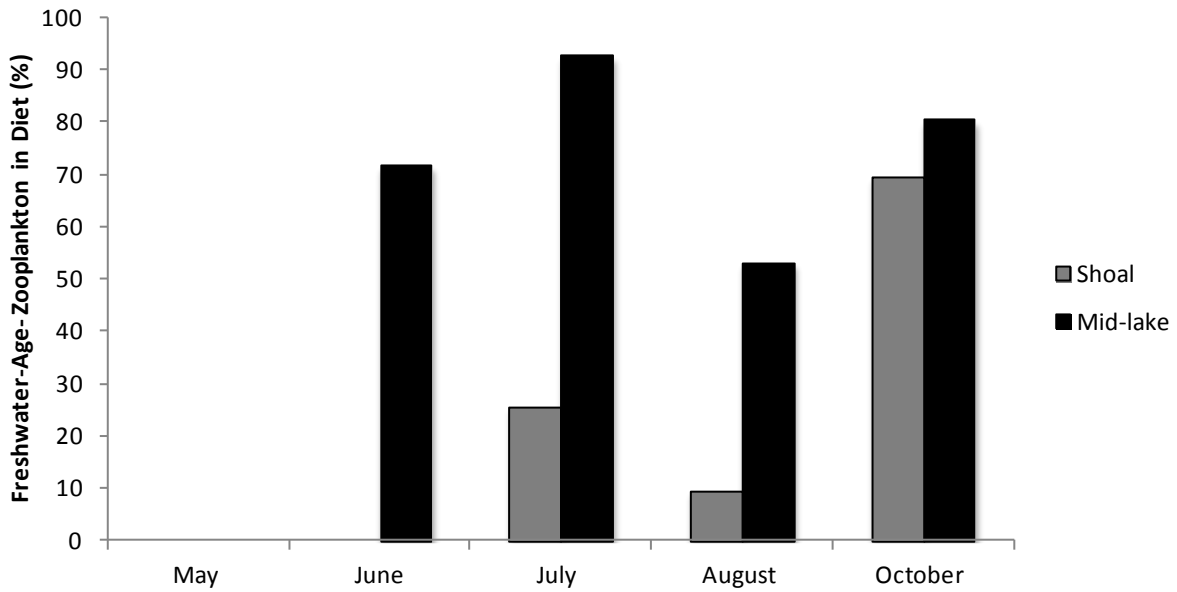


Figure 16.—Percentage of zooplankton within the stomachs of lake rearing freshwater-age-0 juvenile sockeye salmon by location and month from Afognak Lake, 2012.

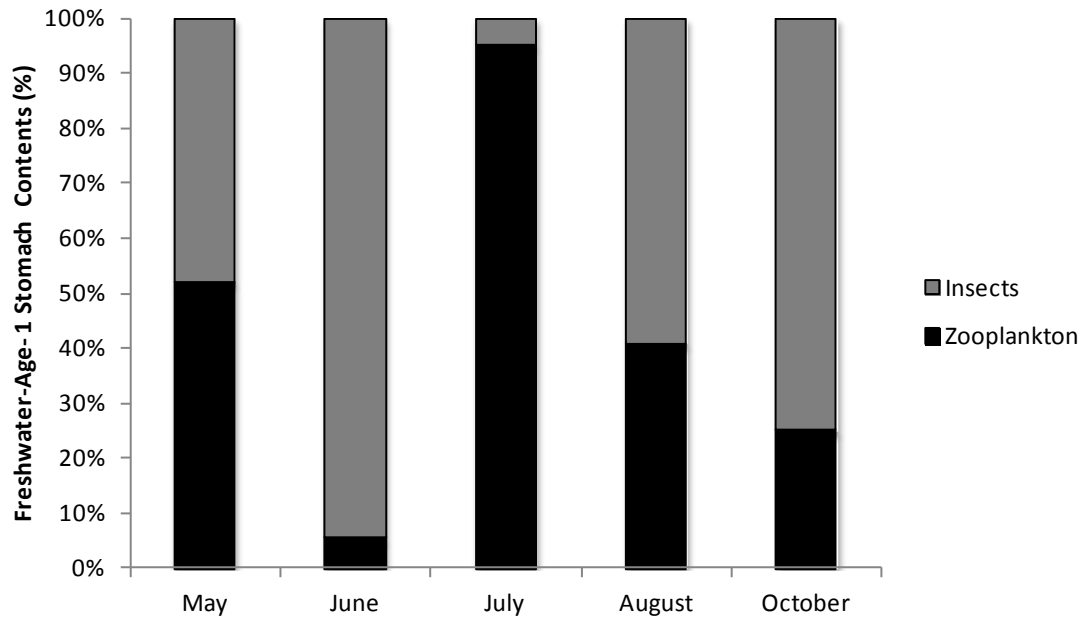


Figure 17.—Percentage of insects and zooplankton within the stomachs of lake rearing freshwater-age-1 juvenile sockeye salmon from Afognak Lake, 2012.

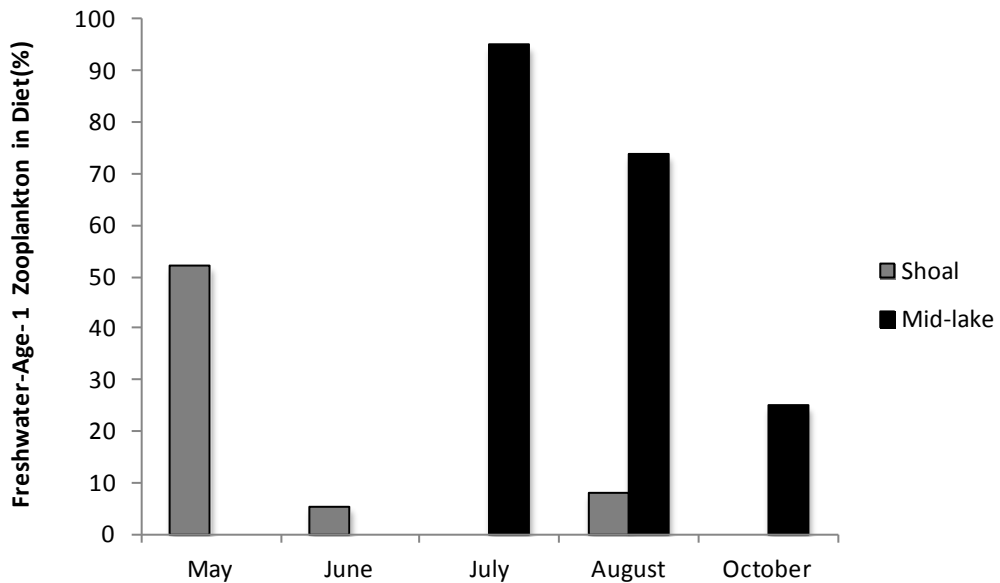


Figure 18.—Percentage of zooplankton within the stomachs of lake rearing freshwater-age-1 juvenile sockeye salmon by location and month from Afognak Lake, 2012.

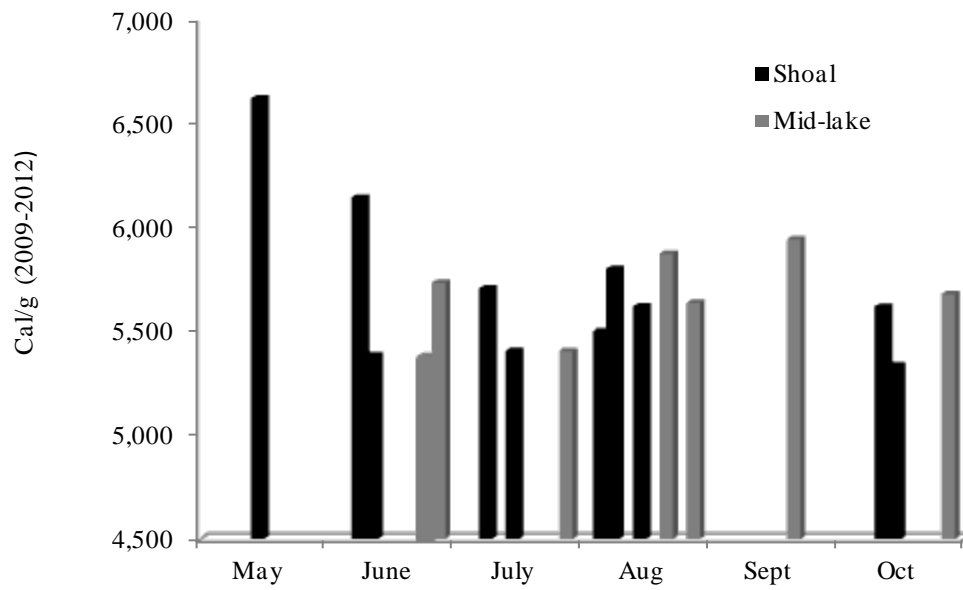


Figure 19.—Mean caloric content (cal/g) of freshwater-age-0 sockeye salmon captured in Afognak Lake by sample date, 2009–2012.

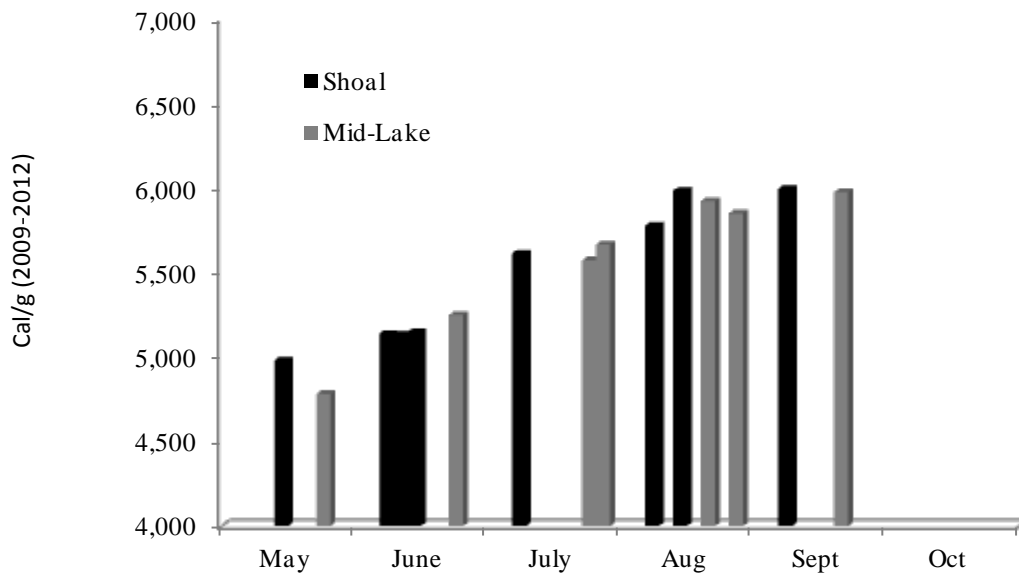


Figure 20.—Mean caloric content (cal/g) of freshwater-age-1 sockeye salmon captured in Afognak Lake by sample date, 2009–2012.

## **APPENDIX A. SUPPORTING HISTORICAL INFORMATION**

Appendix A1.—Population estimates of sockeye salmon smolt outmigrations from Afognak Lake 2003–2012.

Stratum (h)	Starting date	Ending date	Catch ( $u_h$ )	Released ( $M_h$ )	Recaptured ( $m_h$ )	Carlson trap efficiency (%)	Estimate ( $U_h$ )	Variance ( $U_h$ )	95% Confidence Interval	
									lower	upper
2003										
1	5/12	5/19	1,387	239	5	2.1%	55,480	4.31E+08	14,809	96,151
2	5/20	5/25	2,912	239	5	2.1%	116,480	1.89E+09	31,188	201,772
3	5/26	5/31	11,966	706	161	22.8%	52,222	1.31E+07	45,136	59,308
4	6/1	6/7	31,358	638	133	20.8%	149,536	1.31E+08	127,063	172,008
5	6/8	6/10	11,153	686	257	37.5%	29,698	2.18E+06	26,807	32,589
6	6/11	6/18	18,696	679	103	15.2%	122,243	1.21E+08	100,663	143,823
7	6/19	6/26	4,762	506	79	15.6%	30,179	9.63E+06	24,097	36,261
8	6/27	7/3	736	218	17	7.8%	8,955	3.97E+06	5,050	12,859
Total			82,970	3,911	760	19.9%	564,793	2.61E+09	374,814	754,772
							SE=	5.10E+04		
2004										
1	5/11	5/26	24,278	525	56	10.7%	224,039	7.73E+08	169,530	278,548
2	5/27	6/3	17,727	547	96	17.6%	100,148	8.47E+07	82,111	118,186
3	6/4	6/11	16,658	700	211	30.1%	55,081	1.01E+07	48,864	61,299
4	6/12	6/19	5,086	613	119	19.4%	26,023	4.61E+06	21,815	30,231
5	6/20	7/3	3,779	581	88	15.1%	24,712	5.88E+06	19,958	29,466
Total			67,528	2,966	570	18.6%	430,004	8.79E+08	371,905	488,104
							SE=	2.96E+04		

Note: SE = standard error

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Stratum (h)	Starting date	Ending date	Catch ( $u_h$ )	Released ( $M_h$ )	Recaptured ( $m_h$ )	Avg.trap efficiency (%)	Estimate ( $U_h$ )	Variance ( $U_h$ )	95% Confidence Interval	
									lower	upper
2005										
1	5/10	5/21	27,226	489	70	14.3%	184,879	4.05E+08	145,443	224,314
2	5/22	5/26	13,627	518	43	8.3%	155,259	4.89E+08	111,932	198,587
3	5/27	6/5	15,210	482	44	9.1%	158,499	4.94E+08	114,948	202,050
4	6/6	6/27	17,634	368	103	28.0%	61,593	2.58E+07	51,640	71,546
Total			73,697	1,857	260	14.9%	560,230	1.41E+09	486,554	633,906
							SE=	3.76E+04		
2006										
1	5/16	6/1	25,983	312	73	23.6%	110,017	1.24E+08	88,224	131,809
2	6/2	6/6	8,199	515	98	19.2%	42,726	1.49E+07	35,153	50,299
3	6/7	6/16	7,108	485	95	19.8%	35,975	1.09E+07	29,519	42,432
4	6/17	6/29	2,534	492	75	15.4%	16,435	3.06E+06	13,009	19,861
Total			43,824	1,804	341	19.5%	205,153	1.52E+08	180,952	229,353
							SE=	1.23E+04		
2007										
1	5/10	6/5	14,450	415	51	12.5%	115,690	2.22E+08	86,501	144,879
2	6/6	6/12	19,469	202	124	61.5%	31,680	3.09E+06	28,235	35,125
3	6/13	6/20	15,281	510	82	16.2%	94,135	8.88E+07	75,660	112,609
4	6/21	6/27	5,216	541	108	20.1%	25,914	4.98E+06	21,541	30,288
5	6/28	7/4	899	401	44	11.2%	8,031	1.31E+06	5,790	10,272
Total			55,315	2,070	409	19.9%	275,450	3.20E+08	240,388	310,512
							SE=	1.79E+04		

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Appendix A1.–Page 3 of 4.

Stratum (h)	Starting date	Ending date	Catch ( $u_h$ )	Released ( $M_h$ )	Recaptured ( $m_h$ )	Avg.trap efficiency (%)	Estimate ( $U_h$ )	Variance ( $U_h$ )	95% Confidence Interval	
									lower	upper
2008										
1	5/16	5/31	6,516	202	44	21.2%	29,434	1.48E+07	21,903	36,966
2	6/1	6/11	12,500	394	32	8.4%	149,621	6.05E+08	101,411	197,831
3	6/12	6/19	2,559	244	53	22.0%	11,989	2.08E+06	9,162	14,815
4	6/20	7/3	1,290	306	62	20.5%	5,896	4.54E+05	4,575	7,217
Total			22,865	1,147	191	18.3%	196,941	6.22E+08	148,046	245,835
							SE=	2.49E+04		
2009										
1	5/10	5/22	14,338	381	65	17.3%	82,891	8.52E+07	64,799	100,983
2	5/23	6/1	37,537	356	50	14.3%	262,568	1.14E+09	196,454	328,681
3	6/2	6/9	5,829	420	43	10.5%	55,727	6.23E+07	40,261	71,192
4	6/10	6/21	5,753	425	35	8.5%	68,080	1.15E+08	47,025	89,136
5	6/22	7/3	1,510	93	5	6.4%	23,732	7.56E+07	6,686	40,778
Total			64,967	1,674	198	11.4%	492,998	1.48E+09	417,689	568,306
							SE=	3.84E+04		
2010										
1	5/9	5/17	1,026	150	10	7.3%	14,090	1.55E+07	6,373	21,807
2	5/18	5/24	788	385	28	7.5%	10,489	3.52E+06	6,813	14,164
3	5/25	5/31	17,620	274	39	14.6%	120,961	3.06E+08	86,699	155,224
4	6/1	6/7	10,687	275	50	18.5%	57,852	5.27E+07	43,620	72,084
5	6/8	6/14	8,802	228	36	16.2%	54,477	6.58E+07	38,584	70,371
6	6/15	6/21	2,566	464	27	6.0%	42,585	5.94E+07	27,478	57,691
7	6/22	7/1	1,172	488	65	13.5%	8,677	1.03E+06	6,691	10,663
Total						11.9%	309,130	4.43E+08	267,874	350,387
							SE=	21,049		

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Appendix A1.–Page 4 of 4.

Stratum (h)	Starting date	Ending date	Catch ( $u_h$ )	Released ( $M_h$ )	Recaptured ( $m_h$ )	Avg.trap efficiency (%)	Estimate ( $U_h$ )	Variance ( $U_h$ )	95% Confidence Interval	
									lower	upper
2011										
1	5/9	6/5	29,701	511	84	16.6%	178,755	3.11E+08	144,206	213,303
2	6/6	6/13	10,539	200	35	17.9%	58,843	7.71E+07	41,635	76,051
3	6/14	6/20	9,567	462	70	15.3%	62,442	4.62E+07	49,120	75,763
4	6/21	6/27	3,628	169	27	16.5%	21,979	1.40E+07	14,641	29,317
5	6/28	7/6	974	300	36	12.3%	7,930	1.51E+06	5,524	10,336
Total						15.7%	329,949	4.50E+08	288,393	371,502
								SE= 21,201		
2012										
1	5/8	6/1	5,197	350	69	20.0%	26,037	7.75.E+06	20,583	31,492
2	6/2	6/7	4,010	314	43	14.0%	28,744	1.60.E+07	20,911	36,578
3	6/8	6/15	7,933	347	78	22.7%	34,988	1.20.E+07	28,213	41,764
4	6/16	6/23	4,672	438	55	12.8%	36,632	2.08.E+07	27,696	45,568
5	6/24	6/28	280	463	88	19.2%	1,460	2.52.E+04	1,149	1,771
Total						17.7%	127,862	5.65.E+07	98,551	157,173
								SE=7,515		
Mean (2003–2011)						16.7%				
SD (2003–2011)						3.3%				

Appendix A2.—Mean and percent age composition by year of sockeye salmon smolt sampled from outmigrants at Afognak Lake, 2003–2012.

Year	Freshwater Age						Total
	1	%	2	%	3	%	
2003	373,513	66.1%	191,279	33.9%	0	0.0%	564,793
2004	387,584	90.1%	42,420	9.9%	0	0.0%	430,004
2005	521,025	93.0%	39,205	7.0%	0	0.0%	560,230
2006	146,527	71.4%	58,626	28.6%	0	0.0%	205,153
2007	237,383	86.2%	38,067	13.8%	0	0.0%	275,450
2008	92,018	46.7%	104,923	53.3%	0	0.0%	196,941
2009	427,141	86.6%	64,560	13.1%	1,296	0.3%	492,998
2010	237,716	76.9%	71,415	23.1%	0	0.0%	309,130
2011	250,741	76.0%	79,207	24.0%	0	0.0%	329,948
2012	99,541	77.6%	28,321	22.4%	0	0.0%	127,861
Mean							
(2007-2011)	249,000	74.5%	71,634	25.5%	259	0.1%	320,893
Mean							
(2003-2011)	297,072	77.0%	76,634	23.0%	144	0.0%	373,850

Appendix A3.—Mean weight, length, and condition factor by age for sockeye salmon smolt sampled at Afognak Lake, 1987–2001, and 2003–2012.

Year	Sampling Period	Freshwater-Age-1				Freshwater-Age-2			
		Weight n	Length (g)	Condition (mm)	Condition (K)	Weight n	Length (g)	Condition (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0			
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	May 23-June 24	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	May 13-June 26	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	June 7-20	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	May 24-30	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	May 17-23	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	May 31-June 13	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	June 5-11	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	May 24-30	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	May 24-30	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	May 31-June 6	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	May 31-June 13	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	June 11-13	44	7.0	90.1	0.93	17	5.8	85.6	0.92
2002		0				0			
2003	May 12-July 3	1,031	4.2	79.1	0.82	383	4.2	81.4	0.77
2004	May 11-July 3	1,370	3.6	75.7	0.80	81	3.6	78.7	0.74
2005	May 10-June 27	1,248	3.9	76.8	0.84	65	4.2	81.3	0.77
2006	May 16-June 29	765	3.0	70.8	0.83	202	3.8	79.6	0.75
2007	May 21 - July 2	960	2.6	70.4	0.75	129	3.4	76.5	0.74
2008	May 26 - June 28	169	3.4	75.9	0.76	164	4.0	81.7	0.73
2009	May 13 - June 29	1053	3.5	76.7	0.76	205	5.3	88.8	0.75
2010	May 9 - July 1	601	2.6	69.9	0.76	198	3.9	82.1	0.69
2011	May 9 - July 6	757	3.1	71.8	0.81	128	3.7	78.4	0.77
2012	May 8 - June 28	378	3.1	72.5	0.81	134	3.9	79.1	0.78
Avg (1987-2011)		491	3.6	75.1	0.81	115	4.2	80.2	0.80
Avg (2002-2011)		833	3.3	74.0	0.79	169	4.0	80.8	0.75
Avg (2007-2011)		653	3.1	72.9	0.78	160	4.0	81.1	0.74

Appendix A4.—Estimated age composition of the Afognak Lake sockeye salmon escapement, 1985–2012.

Year	Sample Size		Ages								Total
			1.1	1.2	2.1	1.3	2.2	1.4	2.3	3.2	
1985	691	Percent	0.0	26.0	0.0	51.1	14.1	0.4	8.4	0.0	100.0
		Numbers	15	14,027	0	27,506	7,593	206	4,525	0	53,872
1986	484	Percent	0.6	10.1	0.2	74.8	5.8	0.2	8.1	0.0	100.0
		Numbers	300	4,893	100	36,150	2,796	100	3,895	0	48,333
1987	647	Percent	5.2	32.2	1.0	45.3	2.5	0.0	13.8	0.0	100.0
		Numbers	1,376	8,513	257	11,992	660	0	3,645	0	26,474
1988	933	Percent	0.7	59.5	3.2	24.2	11.2	0.0	0.9	0.0	100.0
		Numbers	257	23,227	1,233	9,441	4,363	0	350	0	39,012
1989	543	Percent	8.7	11.4	3.1	50.8	24.1	0.0	1.8	0.0	100.0
		Numbers	7,688	10,142	2,781	45,149	21,429	0	1,636	0	88,825
1990	1,053	Percent	0.7	46.7	0.6	22.6	8.6	0.3	20.5	0.0	100.0
		Numbers	598	42,314	554	20,518	7,754	262	18,614	0	90,666
1991	1,062	Percent	0.3	14.7	0.2	76.6	3.5	0.0	4.6	0.0	100.0
		Numbers	295	13,055	195	67,808	3,099	0	4,105	0	88,557
1992	1,025	Percent	21.2	22.2	9.9	29.9	3.8	0.5	12.3	0.0	100.0
		Numbers	16,360	17,114	7,680	23,096	2,938	394	9,527	0	77,260
1993	852	Percent	16.6	10.7	17.2	30.3	12.3	0.0	12.5	0.2	100.0
		Numbers	11,838	7,634	12,318	21,676	8,815	0	8,965	162	71,460
1994	840	Percent	9.6	30.6	4.1	35.2	10.3	0.1	9.6	0.1	100.0
		Numbers	7,703	24,648	3,337	28,387	8,315	62	7,707	64	80,570
1995	848	Percent	2.3	21.8	0.8	56.3	10.8	0.1	7.8	0.0	100.0
		Numbers	2,282	21,786	838	56,366	10,773	147	7,778	0	100,131
1996	1,119	Percent	16.1	9.2	2.1	44.0	2.1	0.2	26.0	0.1	100.0
		Numbers	16,339	9,398	2,183	44,744	2,094	184	26,428	81	101,718
1997	1,168	Percent	5.1	25.9	6.6	45.8	2.0	0.0	14.6	0.0	100.0
		Numbers	6,704	34,145	8,697	60,416	2,632	41	19,247	0	132,050
1998	1,240	Percent	19.0	8.0	7.1	49.1	10.6	0.4	5.5	0.0	100.0
		Numbers	12,720	5,371	4,767	32,826	7,099	250	3,684	0	66,869
1999	1,195	Percent	1.1	38.8	0.5	9.5	42.7	0.2	6.6	0.5	100.0
		Numbers	1,030	36,992	506	9,043	40,720	232	6,278	455	95,361

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## Appendix A4.–Page 2 of 2.

Year	Sample Size		Ages								Total
			1.1	1.2	2.1	1.3	2.2	1.4	2.3	3.2	
2000	1,161	Percent	2.1	2.5	0.3	15.7	6.0	0.0	69.1	3.3	100.0
		Numbers	1,121	1,348	188	8,484	3,228	0	37,382	1,806	54,064
2001	790	Percent	1.4	11.0	6.2	23.4	3.2	0.0	39.3	0.0	100.0
		Numbers	334	2,681	1,496	5,683	775	0	9,540	0	24,271
2002	238	Percent	0.1	1.0	3.2	32.6	24.7	0.0	4.8	32.8	100.0
		Numbers	19	194	625	6358	4830	0	935	6,399	19,520
2003	498	Percent	4.1	22.6	0.2	0.8	25.7	0.0	29.6	2.8	100.0
		Numbers	1,148	6,273	66	233	7,141	0	8,229	770	27,766
2004	566	Percent	1.1	44.3	0.2	19.0	1.8	0.0	26.8	0.0	100.0
		Numbers	170	6,720	25	2,888	280	3	4,073	0	15,181
2005	572	Percent	3.2	10.0	0.6	82.0	2.2	0.0	1.3	0.0	100.0
		Numbers	683	2,153	136	17,697	472	0	280	0	21,577
2006	613	Percent	2.5	63.1	0.0	22.1	2.6	0.0	9.4	0.0	100.0
		Numbers	569	14,481	0	5,075	596	36	2,156	0	22,933
2007	590	Percent	5.1	32.5	0.3	54.4	2.1	0.0	5.6	0.0	100.0
		Numbers	1,076	6,844	67	11,461	436	8	1,178	0	21,070
2008	643	Percent	4.3	41.6	0.3	49.4	3.7	0.0	0.6	0.0	100
		Numbers	1,165	11,177	87	13,269	1,003	0	173	0	26,874
2009	776	Percent	4.5	39.9	2.7	47.7	2.3	0.0	2.8	0.0	100
		Numbers	1,412	12,520	852	14,969	722	0	884	0	31,358
2010	954	Percent	2.6	15.8	0.2	80.6	0.5	0.1	0.2	0.0	100
		Numbers	1,377	8,234	103	42,108	267	52	114	0	52,255
2011	750	Percent	4.2	40.2	3.3	28.5	8.8	0.3	14.7	0.0	100
		Numbers	2,086	19,771	1,606	14,015	4,340	152	7222	0	49,193
2012	767	Percent	2.3	15.7	0.8	56.7	14.0	0.1	10.4	0.0	100
		Numbers	968	6,531	325	23,565	5,800	48	4315	0	41,553
Avg (1992-2011)		Percent	6.3	24.6	3.3	37.8	8.9	0.1	15.0	2.0	100.0
		Numbers	4,307	12,474	2,279	20,940	5,374	78	8,089	487	54,574
Avg (2002-2011)		Percent	3.2	31.1	1.1	41.7	7.5	0.0	9.6	3.6	100.0
		Numbers	970	8,837	357	12,807	2,009	25	2,524	717	28,773
Avg (2007-2011)		Percent	4.2	34.0	1.4	52.1	3.5	0.1	4.8	0.0	100.0
		Numbers	1,423	11,709	543	19,164	1,353	42	1,914	0	36,150

Appendix A5.–Temperatures (°C) measured at the 1-meter and near bottom strata in the spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake, 1989–2012.

Year	Spring		Summer		Fall	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	7.8	7.0	16.3	12.8	15.3	13.6
1990	9.4	8.3	14.8	13.6	11.9	11.4
1991	6.2	5.7	15.1	12.5	12.4	12.1
1992	10.0	8.9	15.5	13.9	11.1	11.0
1993	11.9	10.4	17.6	14.5	13.5	12.6
1994	10.8	8.8	15.5	13.5	10.2	9.7
1995	8.8	7.3	15.2	12.8	12.5	11.9
1996	11.5	9.7	15.2	13.9	11.1	10.5
1997	10.3	7.5	17.6	10.6	14.1	12.4
1998	7.9	7.7	14.3	13.0	11.8	11.6
1999	7.0	6.2	15.1	11.4	10.4	10.1
2000	9.7	8.7	15.0	13.1	10.1	10.0
2001	9.1	7.0	17.1	10.2	12.9	12.5
2002	10.0	7.8	16.0	10.8	9.3	9.2
2003	9.7	5.5	18.3	12.9	11.5	11.3
2004	9.2	8.2	15.1	11.7	13.1	12.9
2005	11.8	9.5	18.1	13.5	13.6	13.5
2006	9.2	8.0	15.8	12.5	12.6	12.5
2007	9.2	6.7	15.4	9.5	12.4	12.3
2008	8.6	6.9	14.7	13.3	11.9	11.4
2009	11.1	8.4	17.4	13.9	12.4	12.2
2010	8.7	8.1	15.1	14.2	14.9	14.1
2011	8.2	7.4	14.7	12.6	12.1	11.5
2012	10.2	7.6	14.4	12.2	11.8	11.9
Avg						
1989-2011	9.4	7.8	15.9	12.6	12.2	11.7

Appendix A6.–Dissolved oxygen concentrations (mg L<sup>-1</sup>) measured at the 1-meter and near bottom strata in the spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake, 1989–2012.

Year	Spring		Summer		Fall	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	11.7	11.2	10.3	9.2	13.1	10.3
1990	14.0	11.8	9.5	8.6	9.6	8.9
1991	12.6	11.1	10.9	8.2	10.5	9.4
1992	11.5	10.8	10.1	8.7	10.8	10.8
1993	10.9	9.8	9.5	7.5	10.5	10.1
1994	11.0	9.8	10.0	8.1	11.3	10.9
1995	11.4	11.3	10.0	8.4	10.5	9.8
1996	10.9	10.5	10.0	7.7	11.2	11.1
1997	10.5	10.7	9.0	4.6	10.2	7.6
1998	11.8	11.7	10.2	6.1	10.2	10.0
1999	11.9	11.5	9.6	6.2	10.9	10.4
2000	11.0	9.1	9.7	6.8	10.5	10.1
2001	9.7	9.6	9.3	4.7	9.0	8.1
2002	10.8	9.3	9.8	0.1	10.5	10.1
2003	12.0	11.1	9.2	5.5	18.0	10.3
2004	12.9	11.2	11.5	8.1	10.5	6.4
2005	10.8	10.2	9.5	5.1	9.5	8.7
2006	10.9	10.0	9.8	8.3	10.5	10.0
2007	11.4	10.8	9.2	6.6	10.6	9.9
2008	12.5	10.7	9.5	8.9	9.5	9.9
2009	10.9	10.3	9.0	7.9	8.9	8.6
2010	10.8	9.8	9.7	8.8	10.2	9.8
2011	12.2	11.9	10.2	8.4	10.2	9.9
2012	12.1	11.8	10.7	9.7	11.0	10.6
Avg						
1989-2011	11.5	10.7	9.8	7.2	10.7	9.6

Appendix A7.—Average euphotic zone depth (EZD), light extinction coefficient ( $K_d$ ), Secchi disk transparency, and euphotic volume (EV) for Afognak Lake, 1989–2012.

Year	EZD (m)	SD	$K_d$ ( $m^{-1}$ )	SD	Secchi (m)	SD	EV ( $10^6 m^3$ )	SD
1987	8.43	1.14	NA	NA	4.7	1.4	44.65	6.04
1988	11.91	2.78	NA	NA	4.2	0.5	63.14	14.73
1989	13.30	3.28	-0.38	0.10	4.80	0.41	70.50	17.40
1990	9.05	2.90	-0.56	0.23	3.58	0.60	47.98	15.37
1991	10.05	2.80	-0.50	0.18	2.71	0.53	53.28	14.86
1992	10.24	1.78	-0.45	0.07	2.75	0.87	54.27	9.45
1993	9.32	2.32	-0.51	0.11	3.43	0.51	49.38	12.31
1994	7.40	1.40	-0.60	0.10	3.42	0.38	39.20	7.41
1995	7.40	1.33	-0.61	0.12	2.45	0.56	39.21	7.06
1996	7.96	1.70	-0.58	0.14	3.52	0.40	42.19	9.03
1997	8.48	1.32	-0.56	0.12	3.23	0.75	44.92	7.00
1998	7.49	0.76	-0.59	0.07	3.69	1.23	39.68	4.04
1999	8.81	2.92	-0.57	0.12	3.00	0.61	46.71	15.49
2000	9.82	1.60	-0.46	0.07	3.35	0.63	52.07	8.47
2001	11.04	3.35	-0.46	0.12	3.95	1.14	58.52	17.74
2002	10.52	0.57	-0.41	0.02	4.25	0.54	55.75	3.03
2003	9.80	1.31	-0.44	0.05	4.50	0.23	51.95	6.94
2004	9.13	1.27	-0.47	0.06	4.15	0.58	48.39	6.71
2005	9.80	0.83	-0.45	0.05	4.78	0.64	51.96	4.41
2006	9.02	1.02	-0.49	0.07	4.04	0.71	47.83	5.43
2007	9.47	1.17	-0.49	0.08	4.15	0.71	50.17	6.23
2008	9.07	1.47	-0.51	0.08	4.38	0.38	48.08	7.81
2009	9.37	0.41	-0.48	0.03	4.40	0.72	49.65	2.19
2010	10.03	1.29	-0.44	0.06	4.50	0.80	53.16	6.84
2011	8.20	1.12	-0.55	0.09	4.25	0.59	43.46	5.94
2012	9.81	0.59	-0.45	0.03	4.90	0.38	51.99	3.10
Avg								
1987-2011	9.42	1.63	-0.50	0.09	3.88	0.65	49.93	8.65

*Note:* Values are updated to reflect current database calculations (Heather Finkle, ADF&G, Personal Communication). SD = standard deviation.

Appendix A8.–Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1987–2012.

Year	Station	Depth (m)	Sp. Conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
			(umhos cm)	SD	(Units)	SD	(mg L)	SD	(NTU)	SD	(Pt units)	SD	(mg L)	SD	(mg L)	SD	(ug L)	SD
1987	1	1	47	2.6	6.7	0.2	10.0	0.8	0.8	0.3	8	1.7	3.6	0	0.6	0	76	34.9
	1	17	46	2.8	6.7	0.4	9.5	1.0	0.7	0.4	8	2.6	4	0	1	0	58	17.3
1988	1	1	51	5.9	6.7	0.5	10.8	1.3	1.4	1.0	12	2.4	4.7	ND	1.6	ND	50	13.6
	1	15	50	0.5	6.9	0.2	11.3	1.0	1.1	0.8	10	1.3	ND	ND	ND	ND	81	77.7
	2	1	51	3.7	6.9	0.1	10.5	1.7	1.4	1.1	12	3.2	ND	ND	ND	ND	63	22.3
	2	10	50	2.3	6.8	0.1	10.3	0.6	1.5	1.2	9	2.9	ND	ND	ND	ND	96	52.7
	1	1	64	1.9	7.0	0.5	10.6	1.5	2.4	3.5	8	4.4	4.0	0.6	1.1	0.9	44	10.5
1989	1	15	63	1.0	6.9	0.2	10.2	1.6	0.7	0.1	10	0.7	4.3	0.2	1.2	0.8	51	19.3
	2	1	63	0.8	7.0	0.3	10.4	1.3	0.8	0.2	10	1.1	3.8	0.4	1.5	0.6	53	9.1
	2	12	65	3.3	6.9	0.4	10.6	2.2	0.8	0.2	10	1.4	4.4	0.1	1.4	0.3	91	39.1
	1	1	41	1.7	6.8	0.1	6.3	0.5	0.8	0.4	14	3.4	2.9	1.4	0.4	0.3	121	24.3
1990	1	16	41	1.0	6.7	0.2	6.1	0.6	0.7	0.4	11	2.2	3.2	1.8	0.4	0.3	128	38.7
	1	1	38	0.8	6.7	0.1	10.4	7.8	0.9	0.3	13	0.8	2.1	0.3	0.8	0.5	210	31.1
1991	1	14	38	1.0	6.6	0.2	6.9	0.3	0.9	0.2	16	3.9	1.9	0.1	0.8	0.5	190	45.0
	1	1	35	1.2	6.6	0.2	5.8	1.0	0.9	0.5	12	3.4	2.5	0.9	0.6	0.3	157	9.3
1992	1	24	35	0.5	6.3	0.1	4.9	1.0	0.8	0.6	11	1.5	2.5	1.2	0.6	0.3	162	56.9
	1	1	37	1.0	6.6	0.1	7.5	2.7	0.5	0.1	7	7.5	2.2	0.4	1.3	1.1	104	34.9
1993	1	25	39	4.0	6.4	0.4	7.8	2.1	0.5	0.2	10	10.7	2.6	0.9	0.8	0.1	134	52.0
	1	1	39	6.5	6.6	0.2	6.2	2.0	1.1	0.8	5	3.2	2.2	0.9	0.6	0.2	141	44.0
1994	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	26	36	0.9	6.3	0.3	6.5	2.5	0.7	0.3	6	4.7	2.2	0.5	0.6	0.2	197	87.7
	1	1	60	5.6	6.6	0.2	9.8	1.0	2.0	0.8	11	2.6	3.7	1.4	1.3	0.4	85	45.6
	1	17	60	5.4	6.5	0.2	10.0	1.3	2.3	1.2	9	2.0	3.4	0.5	1.6	0.5	101	33.0
1995	2	1	58	4.9	6.6	0.2	9.7	1.1	1.9	0.9	11	4.3	3.2	0.3	1.1	0.3	87	55.9
	2	11	58	4.3	6.5	0.2	9.6	1.1	2.0	0.8	10	5.5	3.5	0.4	1.3	0.3	101	53.9
	1	1	56	1.5	6.7	0.2	10.5	0.7	1.4	1.0	10	2.5	3.2	0.5	1.3	0.2	54	25.9
	1	18	57	2.7	6.6	0.1	11.2	1.9	1.5	0.7	9	0.5	3.1	0.5	1.1	0.3	72	33.2
1996	2	1	56	1.4	6.7	0.1	10.7	1.0	1.2	0.6	9	1.3	3.1	0.5	1.1	0.3	54	25.7
	2	11	57	1.1	6.7	0.1	10.7	1.0	1.5	0.6	11	2.6	2.9	0.5	1.5	0.3	89	43.4

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	Station	Depth	Sp. Conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
Year		(m)	(umhos cm)	SD	(Units)	SD	(mg L)	SD	(NTU)	SD	(Pt units)	SD	(mg L)	SD	(mg L)	SD	(ug L)	SD
1997	1	1	53	0.6	7.1	0.2	12.1	1.6	1.1	0.1	9	1.9	3.1	0.4	1.1	0.3	28	16.6
	1	18	58	6.7	6.8	0.2	13.9	3.5	1.7	0.4	10	0.8	2.9	0.5	1.7	1.1	68	37.7
	2	1	53	0.8	7.1	0.1	11.7	0.5	1.0	0.2	11	3.8	3.0	0.3	1.0	0.3	34	17.3
	2	13	53	0.5	7.0	0.1	11.9	0.3	1.3	0.5	10	3.0	2.9	0.3	1.0	0.3	44	25.8
1998	1	1	49	0.6	7.0	0.1	12.6	1.3	1.7	1.2	18	10.7	3.2	0.5	0.8	0.2	26	15.0
	1	18	48	ND	7.0	ND	11.8	ND	2.0	ND	11	ND	3.3	ND	1.0	ND	48	ND
1999	1	1	58	0.0	6.8	0.2	11.1	0.6	1.6	1.0	11	1.7	3.3	0.3	1.4	0.1	82	43.8
2000	1	1	ND	ND	7.1	0.2	8.7	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2001	1	1	ND	ND	7.2	0.4	10.1	2.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2002	1	1	ND	ND	7.2	0.5	10.1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2003	1	1	ND	ND	6.9	0.1	9.8	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2004	1	1	ND	ND	6.9	0.1	11.4	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	18	ND	ND	6.8	0.1	10.9	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2005	1	1	ND	ND	6.8	0.1	10.9	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2006	1	1	ND	ND	6.8	0.1	11.3	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2007	1	1	ND	ND	6.8	0.1	10.9	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2008	1	1	ND	ND	6.7	0.2	11.4	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2009	1	1	ND	ND	7.0	0.4	11.7	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2010	1	1	ND	ND	7.2	0.1	9.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2011	1	1	ND	ND	7.4	0.1	11.3	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2012	1	1	ND	ND	7.5	0.2	11.1	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Averages:																		
Pre-fertilization yrs.																		
1987-1989			55	3.0	6.8	0.3	10.5	1.3	1.3	1.2	10	2.6	4.0	0.3	1.2	0.5	57	18.1
Fertilization yrs.																		
1990-2000		1	49	2.1	6.8	0.2	9.5	1.7	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
All yrs.																		
1987-2012		1	50	2.3	6.9	0.2	10.1	1.4	1.3	0.8	10	3.3	3.2	0.6	1.0	0.4	81	26.7
Post-fertilization yrs.																		
2001-2012		1	ND	ND	7.0	0.2	10.8	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix A9.–Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1987–2012.

Year	Station	Depth (m)	Total Phosphorus		Total filterable-P		Filterable reactive-P		Total Kjeldahl Nitrogen		Ammonia		Nitrate +Nitrite		Reactive Silicon		Organic Carbon		Chlorophyll <i>a</i>		Phaeophytin <i>a</i>	
			(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD
1987	1	1	8.8	3.6	3.1	1.5	1.6	0.3	130	5.6	5	2.6	135	57.8	3255	719.8	144	30	0.64	0.21	0.54	0.19
	1	17	6.7	1.0	2.8	0.6	1.4	0.2	116	14.5	13	11.7	148	51.6	3313	706.9	102	26	0.32	0.21	0.41	0.02
1988	1	1	8.1	2.2	4.7	1.9	2.7	0.6	140	18.9	4	2.0	60	36.0	2509	344.9	247	52	1.64	1.02	0.74	0.17
	1	15	7.8	1.2	4.1	0.8	2.6	0.1	124	10.6	7	6.3	67	32.9	2528	200.4	179	27	2.13	3.17	0.99	0.83
	2	1	8.0	2.8	5.7	4.4	3.1	0.8	128	17.6	3	1.9	60	31.3	2602	134.1	183	44	1.58	1.22	0.72	0.33
	2	10	7.9	2.3	3.5	1.6	2.3	0.1	133	9.6	8	5.7	54	13.2	2499	107.6	300	176	2.76	3.50	1.02	0.32
1989	1	1	8.3	2.8	4.2	0.6	2.4	0.4	139	17.8	3	3.4	67	47.0	2714	197.7	ND	ND	0.92	0.39	0.54	0.17
	1	15	6.5	0.7	3.9	0.5	2.5	0.2	134	11.1	9	10.8	77	32.3	2803	150.6	ND	ND	0.65	0.34	0.51	0.26
	2	1	7.1	1.6	4.2	0.7	2.8	0.5	126	10.0	3	4.1	70	45.6	2752	209.4	ND	ND	0.75	0.18	0.41	0.18
	2	12	8.8	4.5	4.8	2.1	2.5	0.3	131	30.4	13	16.0	77	40.9	2813	161.1	ND	ND	0.67	0.20	0.51	0.22
1990	1	1	4.5	1.5	2.9	4.2	3.7	1.7	128	16.5	8	3.0	40	29.1	3250	247.5	145	13.0	0.34	0.19	0.17	0.03
	1	16	5.1	2.3	1.3	1.3	2.8	1.1	118	22.7	10	4.2	65	29.1	3390	154.5	144	30.6	0.21	0.03	0.28	0.07
1991	1	1	5.0	2.8	3.2	0.6	2.3	0.4	151	22.6	11	1.8	57	21.3	2865	108.6	ND	ND	0.31	0.21	0.27	0.07
	1	14	4.6	1.5	6.0	3.5	4.5	3.2	138	12.3	14	5.0	70	23.2	2966	156.3	ND	ND	0.22	0.14	0.22	0.08
1992	1	1	3.8	0.5	4.1	2.5	3.1	2.4	135	13.9	3	1.7	62	26.1	3163	158.9	199	64.1	0.44	0.29	0.28	0.13
	1	24	3.9	1.7	4.0	3.2	2.6	1.7	127	12.8	10	4.1	93	23.1	3182	198.0	163	52.9	0.31	0.25	0.28	0.12
1993	1	1	4.5	0.8	3.7	1.3	2.8	0.5	148	18.5	5	2.2	49	30.4	3132	220.6	147	53.3	1.01	0.31	0.36	0.03
	1	25	4.9	1.3	8.5	11.7	6.8	9.9	136	17.3	19	10.1	98	31.7	3380	244.0	121	47.5	0.52	0.21	0.45	0.14
1994	1	1	5.7	0.7	4.5	3.3	3.6	2.3	160	23.8	3	1.7	40	21.4	2843	122.4	114	33.0	0.56	0.26	0.28	0.08
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.56	0.34	0.34	0.10
	1	26	5.3	1.1	4.8	3.9	4.2	3.2	160	17.7	15	9.7	74	23.8	3177	285.5	128	52.1	0.36	0.21	0.27	0.09
1995	1	1	8.7	2.7	3.0	1.5	2.0	1.1	168	21.6	9	14.1	66	22.1	1873	735.0	ND	ND	3.92	2.44	1.13	0.62
	1	17	8.1	2.0	1.9	1.1	1.1	0.4	187	47.1	35	44.3	45	35.0	2046	618.4	ND	ND	3.13	1.75	1.10	0.54
	2	1	7.4	2.1	2.1	1.2	1.7	1.0	169	31.0	9	14.0	54	33.2	1942	753.9	ND	ND	4.20	2.90	1.05	0.65
	2	11	7.2	1.7	2.2	2.0	1.6	1.1	157	26.0	16	17.4	52	34.1	2143	805.6	ND	ND	3.27	2.18	1.05	0.62
1996	1	1	9.2	2.6	3.4	0.7	2.8	0.3	161	34.0	18	13.9	40	29.2	2465	297.2	225	80.3	2.39	1.16	0.82	0.38
	1	18	8.2	2.7	2.4	0.7	2.2	0.3	161	56.5	36	37.6	51	27.8	2663	176.1	190	73.1	1.40	0.56	0.81	0.37
	2	1	8.8	2.6	2.7	0.8	2.2	0.4	160	37.3	8	14.6	41	25.9	2466	275.0	226	52.5	1.77	0.50	0.85	0.36
	2	11	8.4	2.8	3.4	1.6	2.9	1.3	147	41.3	29	24.5	50	25.9	2630	220.7	169	55.7	1.07	0.29	0.77	0.31
1997	1	1	7.3	1.9	2.7	1.0	2.6	0.9	155	33.9	14	14.2	22	23.9	2347	354.4	273	63.8	2.56	1.42	1.51	0.66
	1	18	7.2	1.5	2.6	0.5	2.3	0.4	194	68.6	64	53.3	55	14.5	2995	503.5	197	28.8	1.12	0.50	1.08	0.38
	2	1	6.9	1.7	3.6	1.8	3.1	1.5	156	37.8	13	15.8	17	21.8	2435	351.3	252	62.8	1.68	1.25	1.19	0.83
	2	13	6.5	1.4	2.8	1.9	2.3	0.8	148	38.7	21	12.4	30	20.1	2584	433.5	156	50.6	1.33	1.17	1.06	0.76

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Year	Station	Depth (m)	Total Phosphorus		Total filterable-P		Filterable reactive-P		Total Kjeldahl Nitrogen		Ammonia		Nitrate +Nitrite		Reactive Silicon		Organic Carbon		Chlorophyll <i>a</i>		Phaeophytin <i>a</i>	
			(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD	(ug L)	SD
1998	1	1	9.0	1.7	3.3	0.8	1.9	0.0	193	7.7	21	13.9	38	15.9	2387	73.0	152	118.8	0.10	0.04	0.04	0.02
	1	18	7.5	ND	3.7	ND	1.9	ND	182	ND	25	ND	63	ND	2311	ND	36	ND	0.09	ND	0.03	ND
1999	1	1	17.7	18.3	8.6	10.2	6.8	10.0	247	147.2	36	42.6	124	35.2	2390	431.5	261	122.2	2.94	3.19	0.56	0.35
2000	1	1	9.5	4.3	3.1	1.6	1.8	1.6	57	36.6	19	12.5	72	36.1	ND	ND	ND	ND	2.43	1.46	1.10	0.80
2001	1	1	7.8	5.1	6.4	5.2	8.2	6.7	115	22.2	5	3.6	38	32.5	ND	ND	ND	ND	2.37	0.53	0.30	0.20
2002	1	1	6.4	2.3	4.5	3.1	1.5	0.9	131	15.4	5	2.5	27	18.8	ND	ND	ND	ND	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	ND	ND	6	1.8	54	26.9	ND	ND	ND	ND	1.20	0.20	0.50	0.40
2004	1	1	6.2	3.5	4.3	3.2	2.0	0.7	169	103.8	9	2.8	61	31.5	2764	342.8	ND	ND	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	ND	ND	19	13.2	80	28.4	2914	277.1	ND	ND	0.70	0.35	0.19	0.11
2005	1	1	11.4	4.4	7.6	3.6	3.6	3.1	161	45.6	4	2.0	41	34.8	2701	243.7	ND	ND	1.60	0.68	0.24	0.11
2006	1	1	7.2	4.3	2.2	1.6	2.3	1.1	97	59.6	7	1.7	28	30.8	ND	ND	ND	ND	1.92	0.32	0.50	0.09
2007	1	1	3.6	0.4	1.1	0.3	1.1	0.6	115	32.4	6	0.7	56	39.5	ND	ND	ND	ND	1.47	0.43	0.21	0.08
2008	1	1	3.8	1.1	2.3	1.5	1.6	0.9	113	28.6	6	0.6	65	42.3	ND	ND	ND	ND	1.22	0.66	0.58	0.37
2009	1	1	4.8	1.1	1.3	0.3	1.8	1.0	131	29.7	4	0.8	39	40.0	ND	ND	ND	ND	1.92	0.64	0.63	0.33
2010	1	1	4.4	0.8	2.5	0.4	1.7	0.3	19	15.7	4	0.8	23	32.1	2363	682	ND	ND	1.12	0.16	0.63	0.25
2011	1	1	5.8	0.6	2.5	0.4	4.7	2.0	209	21.3	18	6.9	42	27.2	2440	255	ND	ND	1.19	0.62	0.62	0.23
2012	1	1	3.8	0.2	1.7	0.2	0.8	0.3	299	59.3	6	3.6	34	36.0	2806	236	ND	ND	1.74	0.59	0.12	0.06
<u>Averages:</u>																						
Pre-fertilization yrs.																						
1987-1989	1		8.0	2.6	4.4	1.8	2.5	0.5	133	14.0	3.6	2.8	79	43.5	2766	321.2	191	42.2	1.10	0.61	0.59	0.21
Fertilization yrs.																						
1990-2000	1		7.7	3.1	3.6	2.2	2.9	1.7	156	34.5	12.8	11.8	51	26.5	2581	317.6	199	66.4	1.76	1.12	0.69	0.36
All yrs.																						
1987-2012	1		7.1	2.7	3.6	2.0	2.7	1.5	147	32.9	8.9	6.7	52	31.7	2629	325.8	197	60.8	1.56	0.77	0.56	0.27
Post-fertilization yrs.																						
2001-2012	1		6.0	2.2	3.2	1.7	2.6	1.5	142	39.4	6.6	2.3	42	32.7	2615	351.8	ND	ND	1.52	0.43	0.41	0.20

Appendix A10.—Weighted mean zooplankton density, biomass, size by species for station 1, Afognak Lake, 1987–2012.

Station 1	No.	<i>Epischura</i>			<i>Diaptomus</i>			<i>Cyclops</i>			<i>Bosmina</i>			<i>Daphnia</i>			<i>Holopedium</i>			TOTALS	
		Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )
1987	4	28,835	100	0.91	173	1	1.01	4,127	6	0.65	138,370	134	0.33	3,218	4	0.54	2,574	6	0.52	177,297	251
1988	4	22,360	77	0.91	0	0	-	3,185	5	0.69	106,462	104	0.33	962	2	0.71	1,228	3	0.53	134,197	191
1989	5	16,322	71	0.99	0	0	-	3,663	5	0.66	69,638	59	0.31	1,778	3	0.64	1,347	3	0.48	92,748	141
1990	7	15,378	60	0.95	7	0	0.90	9,987	16	0.68	155,051	134	0.31	3,392	5	0.61	4,944	9	0.47	188,759	224
1991	6	21,278	102	1.02	265	1	0.79	6,606	12	0.74	208,574	193	0.32	4,089	9	0.72	4,025	8	0.50	244,837	325
1992	7	23,468	104	0.99	485	1	0.88	4,807	8	0.68	106,832	108	0.33	5,513	13	0.74	3,306	6	0.45	144,411	240
1993	7	33,893	127	0.94	76	0	0.83	5,960	11	0.72	240,817	247	0.34	7,689	14	0.66	3,715	8	0.50	292,150	407
1994	8	23,713	66	0.85	1,844	7	0.98	10,231	17	0.69	257,749	256	0.33	9,621	18	0.66	7,271	13	0.48	310,429	377
1995	7	16,758	84	1.04	5,596	16	0.87	24,932	39	0.68	212,768	197	0.32	13,740	22	0.62	1,410	2	0.46	275,204	360
1996	5	42,112	223	1.06	191	0	0.49	11,614	19	0.69	350,806	378	0.34	16,072	44	0.78	2,909	5	0.47	423,704	670
1997	6	14,367	69	1.02	5,520	11	0.75	24,567	41	0.69	81,591	66	0.30	11,720	17	0.58	915	1	0.43	138,679	205
1998	4	15,672	62	0.96	1,088	5	1.05	2,070	3	0.67	169,971	144	0.31	10,881	14	0.56	5,441	8	0.42	205,123	236
1999	4	18,737	78	0.97	5,945	24	0.97	6,688	12	0.71	133,175	130	0.33	9,449	20	0.68	2,495	5	0.46	176,489	269
2000	5	57,643	180	0.88	8,121	44	1.09	10,743	16	0.66	114,297	126	0.35	5,042	9	0.64	1,408	2	0.46	116,722	188
2001	5	30,122	66	0.77	2,548	6	0.79	8,121	10	0.61	40,764	33	0.30	1,253	1	0.49	2,638	4	0.43	85,446	120
2002	4	8,174	21	0.82	1,009	3	0.92	6,380	7	0.56	38,256	36	0.32	2,935	3	0.51	557	1	0.41	57,311	71
2003	4	39,743	73	0.73	3,782	7	0.74	3,185	4	0.62	102,110	85	0.30	1,393	2	0.60	1,194	2	0.48	151,407	173
2004	5	23,206	37	0.69	510	1	0.86	6,374	8	0.62	58,598	52	0.31	11,472	16	0.58	2,771	5	0.48	102,931	119
2005	5	21,369	59	0.84	1,592	4	0.83	8,238	10	0.60	82,409	65	0.30	4,979	7	0.57	2,027	3	0.43	120,614	148
2006	5	29,565	92	0.88	3,450	10	0.85	9,915	20	0.76	76,518	61	0.30	8,408	11	0.56	6,348	11	0.46	134,204	205
2007	5	10,913	24	0.78	2,930	9	0.88	7,718	13	0.70	74,257	66	0.31	3,386	5	0.58	1,730	3	0.47	100,934	120
2008	5	16,561	45	0.84	823	2	0.83	2,670	3	0.61	66,762	55	0.30	4,231	7	0.62	3,079	6	0.49	94,126	119
2009	5	13,402	42	0.88	0	0		1,409	2	0.60	31,539	24	0.29	2,866	4	0.54	1,208	2	0.45	50,424	73
2010	5	14,841	48	0.89	212	1	0.82	987	1	0.59	64,830	49	0.29	1,327	2	0.53	1,624	3	0.49	83,821	104
2011	5	16,423	50	0.86	1,911	2	0.61	4,501	6	0.61	43,068	31	0.28	446	1	0.57	2,972	6	0.49	69,321	95
2012	5	23,928	82	0.91	425	1	0.81	3,854	6	0.66	56,359	45	0.30	4,310	7	0.64	1,104	3	0.53	89,980	143
Averages:																					
Pre-fertilization yrs.																					
1987-1989		22,506	83	0.94	58	0	1.01	3,658	5	0.67	104,823	99	0.32	1,986	3	0.63	1,716	4	0.51	134,747	194
Fertilization yrs.																					
1990-2000		25,729	105	0.97	2,649	10	0.87	10,746	18	0.69	184,694	180	0.33	8,837	17	0.66	3,440	6	0.46	228,773	318
All yrs.																					
1987-2011		22,994	123	0.90	1,923	6	0.85	7,547	12	0.66	121,008	113	0.31	5,834	10	0.61	2,765	5	0.47	158,852	217
Post-fertilization yrs.																					
2002-2011		19,420	49	0.82	1,622	4	0.82	5,138	7	0.63	63,835	52	0.30	4,144	6	0.57	2,351	4	0.47	96,509	123

Appendix A11.—Weighted mean zooplankton density, biomass, size by species for station 2, Afognak Lake, 1988–2012.

Station 2	No.	<i>Epischura</i>			<i>Diaptomus</i>			<i>Cyclops</i>			<i>Bosmina</i>			<i>Daphnia</i>			<i>Holopedium</i>			TOTALS	
		Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )	(mm)	(no/m <sup>2</sup> )	(mg/m <sup>2</sup> )
1988	4	10,656	45	0.98	40	0	1.44	809	1	0.70	108,838	110	0.33	1,405	3	0.65	942	3	0.55	122,690	162
1989	5	10,306	35	0.90	0	0	-	1,261	2	0.66	48,235	40	0.30	420	1	0.63	553	1	0.46	60,775	79
1990	7	12,610	48	0.94	0	0	-	3,460	5	0.66	128,277	108	0.31	2,350	4	0.64	4,026	7	0.47	150,723	172
1991	6	19,285	80	0.97	1,274	4	0.89	4,277	8	0.74	154,341	132	0.31	3,347	6	0.65	5,083	10	0.49	187,607	240
1992	7	8,948	34	0.94	144	1	1.00	1,436	2	0.67	82,879	84	0.33	2,521	5	0.70	1,579	3	0.45	97,507	129
1993	7	19,033	70	0.93	773	1	0.69	3,882	5	0.62	175,106	157	0.32	2,570	5	0.67	3,988	7	0.47	205,352	245
1994	8	11,006	40	0.93	783	3	0.91	2,736	4	0.65	125,352	116	0.32	4,321	7	0.64	2,468	4	0.46	146,666	174
1995	7	12,193	44	0.92	1,168	4	0.94	9,054	11	0.61	111,525	98	0.31	8,902	12	0.58	1,152	1	0.4	143,994	170
1996	5	20,892	99	1.02	255	2	1.17	2,930	6	0.77	219,747	239	0.35	4,331	11	0.76	1,571	2	0.46	249,726	359
1997	6	13,677	57	0.97	3,468	7	0.75	3,822	5	0.64	86,060	63	0.29	9,652	13	0.56	924	1	0.41	117,601	146
1998	0																				
1999	0																				
2000	0																				
2001	0																				
2002	0																				
2003	0																				
2004	5	27,192	44	0.70	32	0	0.95	5,125	8	0.66	34,843	27	0.29	2,187	4	0.62	1,624	3	0.44	71,003	84
2005	5	22,282	60	0.83	0	0	-	2,850	4	0.63	49,992	37	0.29	815	2	0.73	900	1	0.38	76,839	104
2006	5	9,408	14	0.68	510	1	0.78	3,083	5	0.70	44,282	31	0.28	3,571	5	0.59	1,274	2	0.43	62,128	59
2007	5	16,269	63	0.95	1,141	4	0.93	6,693	12	0.71	57,065	49	0.31	934	1	0.55	2,049	4	0.50	84,151	133
2008	5	20,786	51	0.81	1,592	8	1.04	2,484	3	0.59	49,260	38	0.29	786	2	0.67	1,314	2	0.44	76,222	103
2009	5	5,149	11	0.77	106	0	0.70	1,645	2	0.64	16,189	10	0.27	1,380	2	0.51	902	2	0.46	25,371	27
2010	5	4,273	6	0.67	0	0		504	1	0.55	25,653	16	0.26	191	0	0.65	1,205	2	0.41	31,826	24
2011	5	12,452	29	0.78	2,017	3	0.71	3,312	6	0.70	55,032	36	0.27	1,077	2	0.59	1,592	3	0.47	75,482	78
2012	5	8,386	29	0.97	1,699	4	0.81	1,964	2	0.61	37,155	28	0.29	743	1	0.57	955	2	0.49	50,902	67
Averages:																					
Pre-fertilization yrs.																					
1988-1989 Avg		10,481	40	0.94	20	0	1.44	1,035	2	0.68	78,537	75	0.32	913	2	0.64	748	2	0.51	91,733	121
Fertilization yrs.																					
1990-2000		14,705	59	0.95	983	3	0.91	3,950	6	0.67	135,411	125	0.32	4,749	8	0.65	2,599	4	0.45	162,397	204
All yrs.																					
1988-2011		14,245	46	0.87	739	2	0.92	3,298	5	0.66	87,371	77	0.30	2,820	5	0.63	1,841	3	0.45	110,315	138
Post-fertilization yrs.																					
2002-2011		14,726	35	0.77	675	2	0.85	3,212	5	0.65	41,540	30	0.28	1,368	2	0.61	1,358	2	0.44	62,878	76

Appendix A12.—Sockeye salmon escapement and adult returns by age for Afognak, 1982–2012.

Brood Year	Escapement	Age Class Returns																Total	
		0.1	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	4.1	2.4	3.3	Return	R/S
1982	123,055	2	0	17	112	5,504	112	0	13,845	762	0	0	371	0	0	0	0	20,726	0.17
1983	40,049	0	0	337	0	9,828	297	0	10,013	4,627	0	0	1,707	0	0	35	0	26,844	0.67
1984	94,463	0	0	1,588	54	24,634	1,307	0	47,110	22,360	0	339	24,078	0	0	0	0	121,471	1.29
1985	53,563	36	96	272	0	10,583	2,902	0	26,542	10,030	0	0	6,568	0	0	65	0	57,094	1.07
1986	48,328	0	0	8,022	35	54,737	717	0	108,494	4,958	0	428	10,370	0	0	0	0	187,760	3.89
1987	25,994	0	0	773	0	20,889	313	0	25,139	3,198	99	0	9,772	177	0	0	0	60,359	2.32
1988	39,012	0	0	472	0	18,628	8,360	0	23,626	9,607	57	77	9,686	80	0	0	0	70,593	1.81
1989	88,825	0	0	17,807	0	8,321	13,427	0	35,677	10,450	157	253	13,374	0	0	397	0	99,863	1.12
1990	90,666	0	0	12,902	0	30,978	4,194	0	96,927	18,526	0	397	56,869	175	0	0	199	221,167	2.44
1991	86,819	0	280	9,681	277	37,463	1,440	0	96,284	4,507	0	48	22,573	0	0	0	0	172,552	1.99
1992	75,370	0	0	3,925	175	20,223	4,698	0	70,857	3,087	0	365	5,377	0	0	0	0	108,706	1.44
1993	68,782	0	0	35,159	0	40,046	10,200	0	47,921	10,364	222	330	8,915	646	0	0	680	154,484	2.25
1994	79,380	0	0	7,863	0	7,842	6,959	74	12,841	57,821	74	0	52,384	2,531	0	0	205	148,593	1.87
1995	98,609	0	0	18,569	0	52,527	718	0	11,888	4,523	0	0	11,396	0	75	0	0	99,696	1.01
1996	100,266	0	0	1,463	0	1,888	264	0	6,789	925	4,213	0	996	6,818	0	0	3,992	27,348	0.27
1997	129,481	0	30	1,571	0	3,202	1,787	0	6,775	5,147	171	0	8,408	787	0	186	875	28,938	0.22
1998	65,809	0	0	399	0	207	666	0	238	7,296	0	3	4,225	0	0	0	0	13,033	0.20
1999	94,011	0	0	20	0	6,409	67	0	2,996	291	0	0	293	0	0	0	0	10,076	0.11
2000	52,648	0	0	1,173	0	6,971	26	0	18,560	495	0	36	2,199	0	0	0	0	29,460	0.56
2001	23,940	0	0	177	164	2,258	142	0	5,176	608	0	8	1,202	0	0	0	0	9,735	0.41
2002	19,334	0	0	716	20	14,769	0	0	11,665	435	0	1	196	0	0	0	0	27,803	1.44
2003	27,448	0	0	580	0	7,074	71	0	14,358	1,054	0	1	890	0	0	0	0	24,028	0.88
2004	15,181	0	0	1,105	0	11,631	90	0	15,538	710	0	64	140	0	0	0	0	29,278	1.93
2005	20,281	0	0	1,238	0	13,151	911	0	51,698	328	0	200	9,530	0	0	0	0	77,056	3.80
2006	21,488	0	0	1,492	0	10,108	127	0	18,494	5,727	0	54	4,876	0	0			40,878	1.90
2007	20,066	0	0	1,691	0	26,090	2,119	0	26,626	6,553	0							63,079	3.14
2008	26,052	0	0	2,753	0	7,379	367											10,499	0.40
2009	30,818	0	0	1094														1,094	0.04
2010	51,831	0																	
2011	48,588																		
2012	41,553																		
<b>Averages:</b>																			
Pre-fertilization yrs.																			
1982-1989	64,161	5	12	3,661	25	19,141	3,429	0	36,306	8,249	39	137	9,491	32	0	62	0	80,589	1.54
Fertilization yrs.																			
1990-2000	85,622	0	28	8,430	41	18,887	2,820	7	33,825	10,271	425	107	15,785	996	7	17	541	92,187	1.12
All yrs.																			
1982-2005	65,055	2	17	5,243	35	17,073	2,486	3	31,706	7,588	208	106	10,897	467	3	28	248	76,111	1.38
Post-fertilization yrs.																			
2001-2005	21,237	0	0	763	37	9,776	243	0	19,687	627	0	55	2,392	0	0	0	0	33,580	1.69

Note: Escapement reflects egg take removals. Years after 2005 not fully recruited.

Appendix A13.–Temperatures (°C) logged at station 2, 1 meter, for Afognak Lake, 2011.

Month	Mean	Max	Min	Daily Variation	
				Mean	Max
May	7.3	9.9	6.6	0.4	1.4
June	11.0	13.7	8.5	0.5	1.6
July	15.1	17.1	13.1	0.7	1.5
August	15.8	17.6	14.5	0.4	1.1
September	12.4	14.8	10.7	0.3	0.6
October	10.4	10.7	10.0	0.2	0.3

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
Spring	9.1	13.7	6.6	0.5	1.6
Summer	15.4	17.6	13.1	0.5	1.5
Fall	11.4	14.8	10.0	0.2	0.6

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
(May-Oct)	12.8	17.6	6.6	0.5	1.6

Appendix A14.–Temperatures (°C) logged at station 2, 1 meter, for Afognak Lake, 2010.

Month	Mean	Max	Min	Daily Variation	
				Mean	Max
May	7.3	9.2	5.9	0.5	1.3
June	11.3	13.5	8.8	0.5	1.6
July	14.0	15.7	12.4	0.5	1.4
August	14.8	16.1	14.0	0.5	1.1
September	14.3	15.7	11.8	0.3	1.0
October	9.9	11.8	8.2	0.3	0.4

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
Spring	9.3	13.5	5.9	0.5	1.6
Summer	14.4	16.1	12.4	0.5	1.4
Fall	12.1	15.7	8.2	0.3	1.0

Season	Mean	Max	Min	Daily Variation	
				Mean	Max
(May-Oct)	12.3	16.1	5.9	0.4	1.6

Note: Mean variation is the monthly mean difference between daily maximum and minimum temperatures. Max variation is the monthly maximum difference between daily maximum and minimum temperatures.

Appendix A15.– Summary of Afognak Lake phytoplankton seasonal mean biomass, by phylum, 2010–2012.

		Phylum							
		Chlorophyta (Green Algae)	Chrysophyta (Golden-brown Algae)	Bacillariophyta (Diatoms)	Cryptophyta (cryptomonads)	Pyrrophyta (Dinoflagellate)	Haptophyta	Cyanobacteria (Blue-green Algae)	Total
Date	Station	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )	Biomass (mg/m <sup>3</sup> )
2010	1	0.68	13.50	38.01	7.79	64.74	0.03	1.78	126.53
2011	1	17.37	267.45	228.80	40.01	42.11	8.77	50.28	654.79
2012	1	52.43	0.00	728.39	134.37	209.87	0.00	18.03	1143.09
Mean		23.49	93.65	331.73	60.72	105.57	2.93	23.36	641.47

Appendix A16.– Freshwater-age-0 juvenile weight, length, condition, calorie content, and stomach content by year, month, and location from Afognak Lake, 2009–2012.

Freshwater- Age-0														
Date			Sample	Weight (g)		Length (mm)		Condition		Cal/g		Somach Contents		
Year	Month	Location		Mean	Error	Mean	Error	Mean	Error	Mean	Error	% Full	% Zoo	% Insects
2009	August	Shoal	28	1.1	0.39	45.2	6.04	1.18	0.12	5499.3	274.35	72.9	50.4	49.6
2010	June	Shoal	21	0.5	0.48	35.2	6.19	0.90	0.19	6141.5	375.13	93.6	3.7	96.3
	July	Shoal	23	0.9	0.39	43.6	6.34	1.03	0.14	5704.5	117.13	69.2	36.8	63.2
	August	Shoal	17	2.2	0.64	54.6	6.39	1.29	0.16	5798.5	128.49	48.8	75.0	25.0
	August	Mid-Lake	76	2.1	0.57	55.2	4.75	1.25	0.09	5872.2	150.99	52.0	47.6	52.4
	September	Mid-Lake	22	2.3	0.65	55.6	5.47	1.29	0.12	5940.9	171.54	50.6	88.8	11.2
2011	June	Shoal	18	2.3	0.47	62.2	5.06	0.96	0.09	5382.7	237.30	73.8	18.8	81.3
	June	Mid-Lake	14	2.5	0.56	61.9	4.62	1.07	0.25	5368.6	237.21	40.0	22.5	77.5
	October	Shoal	1	1.8		60.0		0.83		5616.9				
2012	May	Shoal	1	0.3		34.0		0.76		6618.1				
	June	Mid-Lake	8	0.5	0.20	35.5	4.00	1.02	0.32	5731.5	318.50	50.7	71.6	28.4
	July	Shoal	125	1.0	0.53	44.4	6.61	1.03	0.17	5404.2	359.68	66.4	25.6	73.3
	July	Mid-Lake	3	0.6	0.1	39.3	2.08	0.98	0.04	5403.0		62.5	92.5	7.5
	August	Shoal	76	2.0	0.68	55.3	6.26	1.16	0.12	5618.2	271.54	66.1	9.7	90.3
	August	Mid-Lake	49	1.6	0.54	52.5	5.92	1.05	0.08	5635.1	149.21	72.9	53.1	47.4
	October	Shoal	4	2.2	0.43	60.0	3.56	1.01	0.02	5335.3		66.7	69.3	30.7
	October	Mid-Lake	24	2.0	0.61	57.5	5.71	1.02	0.11	5676.7	170.78	49.7	80.2	19.8
2009	Mean	Shoal	28	1.1	0.39	45.2	6.04	1.18	0.12	5499.3	274.35	72.9	50.4	49.6
2010	Mean	Shoal	61	1.2	0.50	44.5	6.31	1.07	0.16	5881.5	206.92	70.5	38.5	61.5
	Mean	Mid-Lake	98	2.2	0.61	55.4	5.11	1.27	0.10	5906.6	161.27	51.3	68.2	31.8
2011	Mean	Shoal	19	2.1	0.47	61.1	5.06	0.90	0.09	5499.8	237.30	73.8	18.8	81.3
	Mean	Mid-Lake	14	2.5	0.56	61.9	4.62	1.07	0.25	5368.6	237.21	40.0	22.5	77.5
2012	Mean	Shoal	206	1.4	0.55	48.4	5.47	0.99	0.10	5452.6	315.61	66.4	34.9	64.8
	Mean	Mid-Lake	84	1.2	0.36	46.2	4.43	1.02	0.14	5611.6	212.83	58.9	74.3	25.8
2009–2012	Mean	Shoal	314	1.4	0.48	49.8	5.72	1.04	0.12	5583.3	258.54	70.9	35.6	64.3
	Mean	Mid-Lake	196	2.0	0.51	54.5	4.72	1.12	0.16	5628.9	203.77	50.1	55.0	45.0

Appendix A17.– Freshwater-age-1 juvenile weight, length, condition, calorie content, and stomach content by year, month, and location from Afognak Lake, 2009–2012.

Freshwater- Age-1														
Date			Sample	Weight (g)		Length (mm)		Condition		Cal/g		Somach Contents		
Year	Month	Location		Mean	Error	Mean	Error	Mean	Error	Mean	Error	% Full	% Zoo	% Insects
2010	June	Shoal	28	2.7	0.58	66.0	2.53	0.94	0.11	5137.6	150.47	68.6	0.6	99.4
	July	Shoal	26	4.0	0.83	71.1	3.71	1.10	0.10	5614.5	294.94	75.0	21.3	78.7
	August	Shoal	39	4.9	0.62	74.1	2.30	1.19	0.09	5779.6	304.22	55.0	45.1	54.9
	August	Mid-Lake	9	4.6	0.48	71.8	3.46	1.24	0.09	5924.1	117.62	32.5	65.0	35.0
	September	Shoal	1	4.7		74.0		1.16		5996.9				
	September	Mid-Lake	3	4.9	0.78	74.0	3.00	1.21	0.06	5976.3	184.29			
2011	May	Mid-Lake	20	2.5	0.74	65.8	6.81	0.87	0.66	4782.0	487.69	38.8	22.5	77.5
	June	Shoal	19	3.3	0.55	70.8	4.69	0.93	0.60	5133.1	199.43	22.5	45.0	55.0
	June	Mid-Lake	15	3.2	0.49	68.0	4.60	1.00	0.11	5249.6	165.41	77.5	5.0	95.0
	August	Mid-Lake	2	4.3	0.71	73.5	7.78	1.09	0.17	5573.6	526.91			
2012	May	Shoal	13	1.9	0.47	61.8	4.94	0.82	0.18	4982.1	67.94	33.1	52.1	47.9
	June	Shoal	25	2.7	0.73	66.6	5.93	0.89	0.11	5148.1	252.59	93.5	5.4	94.6
	July	Mid-Lake	2	4.6	0.92	73.5	7.78	1.15	0.13	5666.1		80.0	95.0	5.0
	August	Shoal	20	5.9	0.55	80.2	1.98	1.14	0.10	5986.0	68.44	60.0	8.0	92.1
	August	Mid-Lake	5	5.7	0.4	79.2	1.30	1.14	0.04	5851.7		68.8	73.8	26.3
	October	Mid-Lake	2	4.7	0.57	77.5	2.12	1.01	0.04			37.5	25.0	75.0
2010	Mean	Shoal	94	4.1	0.67	71.3	2.85	1.10	0.10	5632.1	249.88	66.2	22.3	77.7
	Mean	Mid-Lake	12	4.8	0.63	72.9	3.23	1.23	0.07	5950.2	150.96	32.5	65.0	35.0
2011	Mean	Shoal	19	3.3	0.55	70.8	4.69	0.93	0.60	5133.1	199.43	22.5	45.0	55.0
	Mean	Mid-Lake	37	3.3	0.65	69.1	6.40	0.99	0.31	5201.7	393.34	58.2	13.8	86.3
2012	Mean	Shoal	58	3.5	0.58	69.5	4.28	0.95	0.13	5372.1	129.66	62.2	21.8	78.2
	Mean	Mid-Lake	9	5.0	0.63	76.7	3.73	1.10	0.07	5758.9		62.1	64.6	35.4
2009–2012	Mean	Shoal	171	3.6	0.60	70.5	3.94	0.99	0.28	5379.1	192.99	50.3	29.7	70.3
	Mean	Mid-Lake	58	4.4	0.64	72.9	4.45	1.10	0.15	5636.9	272.15	50.9	47.8	52.2

Appendix A18.– Freshwater-Age-2 juvenile weight, length, condition, calorie content, and stomach content by year, month, and location from Afognak Lake, 2009–2012.

Freshwater-Age-2														
Date			Sample Size	Weight (g)		Length (mm)		Condition		Cal/g		Somach Contents		
Year	Month	Location		Mean	Error	Mean	Error	Mean	Error	Mean	Error	% Full	% Zoo	% Insects
2010	June	Shoal	1	5.0		81.0		0.94		4894.0				
2012	May	Shoal	6	3.2	0.27	74.3	3.01	0.79	0.07	4731.9	53.12	35.0	37.8	62.3
	June	Shoal	4	3.6	0.87	75.3	4.99	0.83	0.07	4861.2	104.78	25.0	0.0	100.0
2010	Mean	Shoal	1	5.0		81.0		0.94		4894.0				
2012	Mean	Shoal	10	3.4	0.57	74.8	4.00	0.81	0.07	4796.5	78.95	30.0	18.9	81.1
2009–2012	Mean	Shoal	11	4.2	0.57	77.9	4.00	0.88	0.07	4845.3	78.95	30.0	18.9	81.1